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ON THE

ORGANS OF VISION.

ON THE

ORGANS OF VISION:

THEIR

ANATOMY AND PHYSIOLOGY.

BY

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ETC. ETC. ETC.

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PREFACE.

Whatever of merit or demerit may be thought to belong to the following work, the Author cannot plead guilty to the charge of hasty conception or hurried publication, and so claim indulgence; he does, however, ask that in estimating its defects, whether of omission or commission, it should be borne in mind the work has been written amidst the constant interruption and distraction of active practice, which has occupied the whole of the day, leaving only the night for scientific investigation. Indeed, an apology is due for the delay which has taken place; the work ought and would have appeared as announced more than twelve months ago, had he not been engaged in the two important trials of Palmer and Dove, which, from the comparative newness of the subject, and the very little that was known, as the evidence for the prosecution on the trial of the first, as to the physiological action of the substance alleged to have been used, showed, fully occupied him in experiments and analyses, to the exclusion of all else except daily practice, as he thought it his bounden duty to the best of his ability to investigate the matter before appearing as a witness where the lives of the prisoners were supposed to depend upon the scientific evidence; and when these trials were over he felt desirous of again going over the whole of the microscopical anatomy of the tissues of the eye.

The Pathology of the Eye,—its diseases and their treatment, has been, perhaps more than any other part of our common Profession, abundantly illustrated and explained in magnificent and copious works, as well as in excellent manuals, in almost all ages, languages, and countries, so that if the subject be not exhausted, the student certainly has not the excuse of want of material readily accessible for understanding the diseases of the eye. The same however can hardly be said for the basis whereon the superstructure for successful treatment must rest; for though the anatomy of the eye has frequently been described and figured in an elaborate and masterly manner in superb and costly books, and in detached and fragmentary essays and papers of almost countless number, by some of the greatest Professors of our Science; yet as a student, almost thirty years ago, and as a teacher nearly ever since, the Author has felt there is no one work to which the student could refer for that explanation of the ideas obtained by sight and its relation to intellectual man; of the nature and elementary laws of light; of some of the more common optical instruments, which in their structure are analogous with the eye; of the more interesting and important of the phenomena of vision; as well as of the descriptive and minute anatomy of the organ, with all of which, if he is to be an intelligent and successful practitioner, he ought to be acquainted. If there be such a work he confesses not to know it, and therefore the present attempt to supply what his experience has induced him to consider a want. Whatever the cause may be, he believes, most who are willing fairly to criticise, and impartially to estimate, the extent of the information they have stored up as the groundwork for the treatment of diseases when they emerge from the student into the practitioner, will confess their knowledge of this part of their profession is not of that clear and comprehensive character as it is of some other branches of their study. If his labour help by furnishing the means within a moderate compass of making the comparison more in favour of the structure and physiology of the eye, he will feel that his object has been accomplished.

In portions of the subject treated of the reader must not expect to find absolutely new matter, that would be impossible, all that has been attempted has been to select from acknowledged authorities such illustrations as should best serve his purpose. Many of these have now become the common property of the world, to have attempted new for an appearance of novelty, when there could not have been improvement, would have been to have risked that which has been proved to be good, for what, very possibly, might have been very imperfect. He has thought it better to make this general acknowledgment here than to load the pages and perplex the reader by constant references to works, particularly as in many instances it is difficult, if not impossible, to trace the idea to the original source, so frequently have many of the figures been repeated from one to another.

For the anatomy he must take the responsibility, nothing so far as he recollects has been described that he has not dissected. In the coarser demonstrations he hopes his descriptions will be found clear and accurate, he pretends to little that is novel, after the works of Zinn, Soemmerring, and Arnold, not to mention others, it can hardly be said to admit of it. The microscopic anatomy of the eye is confessedly a most difficult subject. Indeed no one who is not accustomed to such inquiries can properly estimate the amount of labour and time spent in the investigation. In this part of the subject he has taken nothing at second-hand, every figure and description is the result of repeated observation, in which he has taken pains to be correct: that he has by any means always succeeded he is very far from assuming to be the case. Where the subject is so comparatively new, so exceedingly complex and minute; where the parts are so changeable, and in some instances, as the human retina, so very difficult to be obtained in a state suitable for examination; and where the most experienced and trustworthy observers have not only differed from each other but from themselves, it will probably be some time before unanimity, arising from absolute truth, will be arrived at. He presumes however to say that while this work is intended for the instruction of students, he would appeal to the candid consideration of those, who from their knowledge of microscopical anatomy are best qualified to give an opinion, in support of that which may be proved to be true, and correction of that which is not so, feeling confident they will not overlook the endeavour to be correct, and will not criticise too harshly that which may be faulty.

To enumerate all the authors to whom he is indebted would be as impossible as it is unnecessary. He would, however, mention the following as those to whom he is most so, and to whose works he would refer those who wish to investigate the subject further. Locke on the Human Understanding; Hartley's Observations on Man; Brown's Lectures on the Philosophy of the Human Mind; Reed's Inquiry into the Human

Mind; Stewart's Philosophy of the Human Mind; Abercrombie on the Intellectual Powers; Porterfield on the Eye; the Manner and Phenomena of Vision; Wells on Vision; Brewster on Optics, and in Philosophical Transactions for 1835 and 1836; Herschel, art. Light, in Encyclopædia Metropolitana; Dr. Young's Works, by Dean Peacock; Mackenzie, Philosophy of Vision; Lardner's Handbook of Natural Philosophy—Optics; Ross on the Microscope, in Penny Cyclopædia; Quekett on the History of the Microscope; Hogg on the Microscope; Wheatstone on the Stereoscope, in Philosophical Transactions for 1838 and 1852; Lieuwenhock, the Select Works of, by Hoole; Ruyschii Opera; Zinn, Descriptio Anatomica Oculi Humani; Soemmerring, Icones Oculi Humani; Demours, Traité des Maladies des Yeux (the repetition in which of the plates of Soemmerring are not less beautiful than in the capital original); Arnold, Icones Organ. Sensuum; also good figures of excellently prepared parts; Home, Lectures on Comparative Anatomy; Dr. Jacob's Inquiries respecting the Anatomy of the Eye, in Medico-Chirurgical Transactions, vol. xii.; Swan on the Nerves; Quain's Anatomical Plates; Bell on the Nerves, and also on the Hand; Dalrymple's Anatomy of the Human Eye; Müller's Physiology, by Baly; Hassell's Microscopical Anatomy of the Human Body; Hannover, Recherches Microscopiques sur le Système Nerveux; Bowman's Lectures on the Eye; Kolliker's Manual of Human Histology, by Busk and Huxley; Lister on the Contractile Tissues of the Eye, in Microscopical Journal, vol. i.; Dr. Allen Thompson, Remarks on Dr. Paxton's own case of Unusual Mobility of the Iris, Glasgow Medical Journal, January, 1857; Owen, various articles in Cyclopædia of Anatomy and Physiology; Grant's Comparative Anatomy; Jones's Animal Kingdom; Buckland's Bridgewater Treatise; Kirby and Spence's Introduction to Entomology.

The wood engravings and the plates the Author thinks will be found worthy of commendation as equal at the least to those found in any similar work. These are the production of Mr. Tuffen West, whose skill in the representation of microscopic objects is now well known.

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DESCRIPTION OF PLATES.

PLATE I.

Fig. 1. Human conjunctiva, from the sclerotic, near the junction of it with the cornea; *a*, connective tissue; *b*, epithelial cells; × 260.

Fig. 2. Human conjunctival epithelium;—outer layer of cells covering the cornea; × 450.

Fig. 3. Sheep's eye. Section of junction of cornea and iris: the inner surface of cornea, the anterior of iris, and the manner in which the elastic lamina of the cornea forms the pillars of the iris are seen; *a* elastic layer; this near to the margin of cornea is thrown into folds which contain some colouring matter, these folds are continued in *b*,—the pillars of the iris, which contain still more colouring matter; *c* iris, in the anterior surface of which these pillars are lost.

Fig. 4. Section of staphylomatous cornea just removed from the eye of a boy, on account of its great protrusion: a large part of its opacity was made up of an immense number of epithelial cells,—*a*; *b* fibrous portion of cornea, where besides the usual horizontal layers there was a great number of fibres which passed in every direction obliquely into and were lost at irregular distances in them; and deeper still were fibres not well defined, which on the addition of acetic acid, swelled and became transparent with nuclei *c*, like the sclerotic; into which in fact, the cornea had become converted; × 260.

Fig. 5. Small epithelial cells lying in a single layer on the inner surface of this cornea; the elastic layer had disappeared altogether.

Fig. 6. Epithelial cells from inner surface of cornea of sheep, immediately after death; × 260.

Fig. 7. Same cells on addition of acetic acid, when they present a very strong resemblance in form, size, and nuclei to the cells of the cartilaginous sclerotic of fowl; × 450.

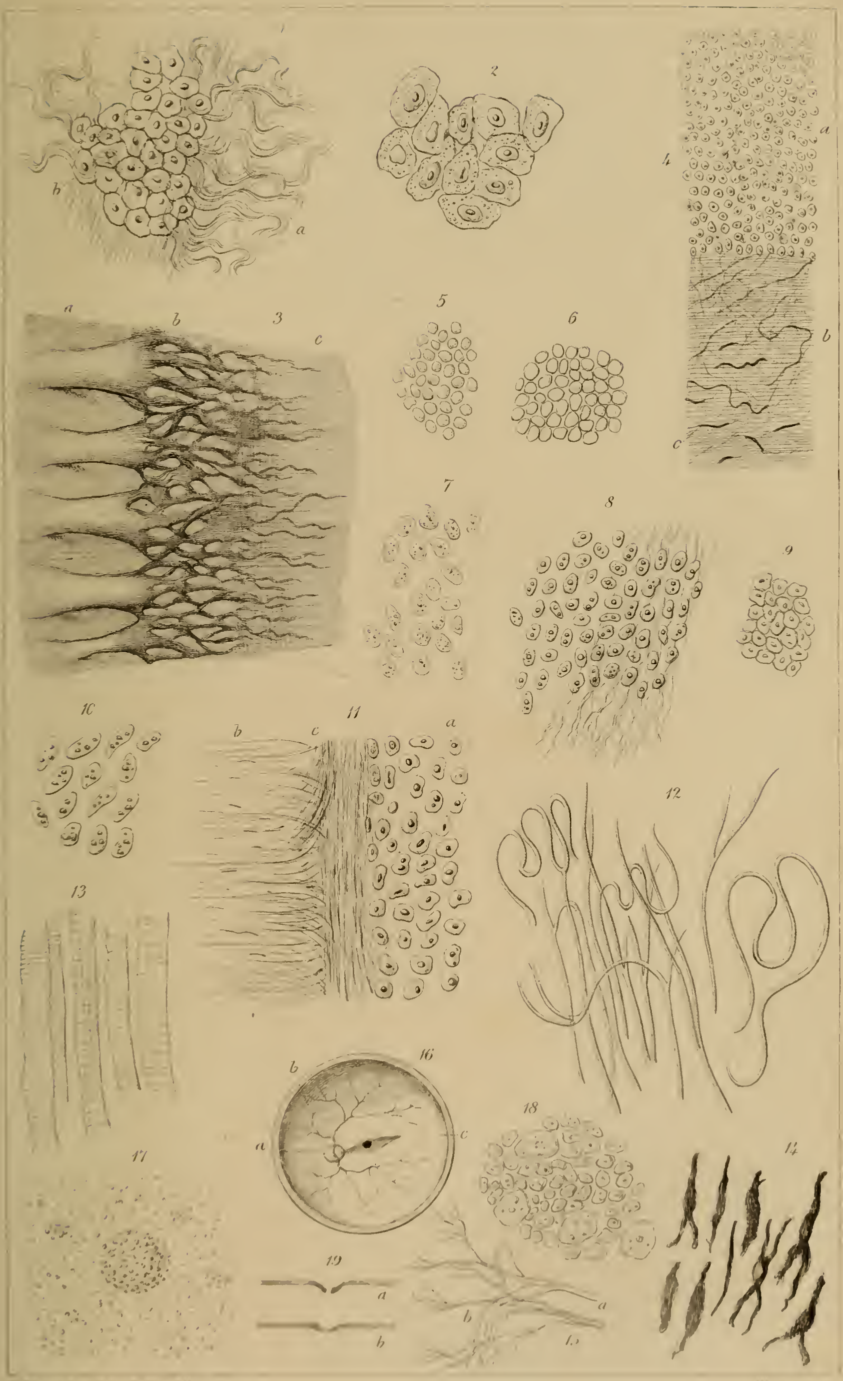
Fig. 8. Sclerotic of common fowl. *a* cartilaginous cells of inner portion of the coat; *b* fibres of white fibrous tissue forming the outer portion of the coat; × 260.

Fig. 9. Epithelial cells from inner surface of cornea of toad; × 260.

Fig. 10. Cartilaginous cells from inner surface of posterior part of sclerotic of toad. The outer surface is fibrous; × 260.

Fig. 11. Haddock; (*gadus æglefinus*) junction of sclerotic and cornea, seen from the inner surface. The cartilaginous sclerotic suddenly ceases, the fibrous middle layer of the cornea abruptly begins; but at the junction

PLATE I.



T. Nunneley del. Tuffen West sc.

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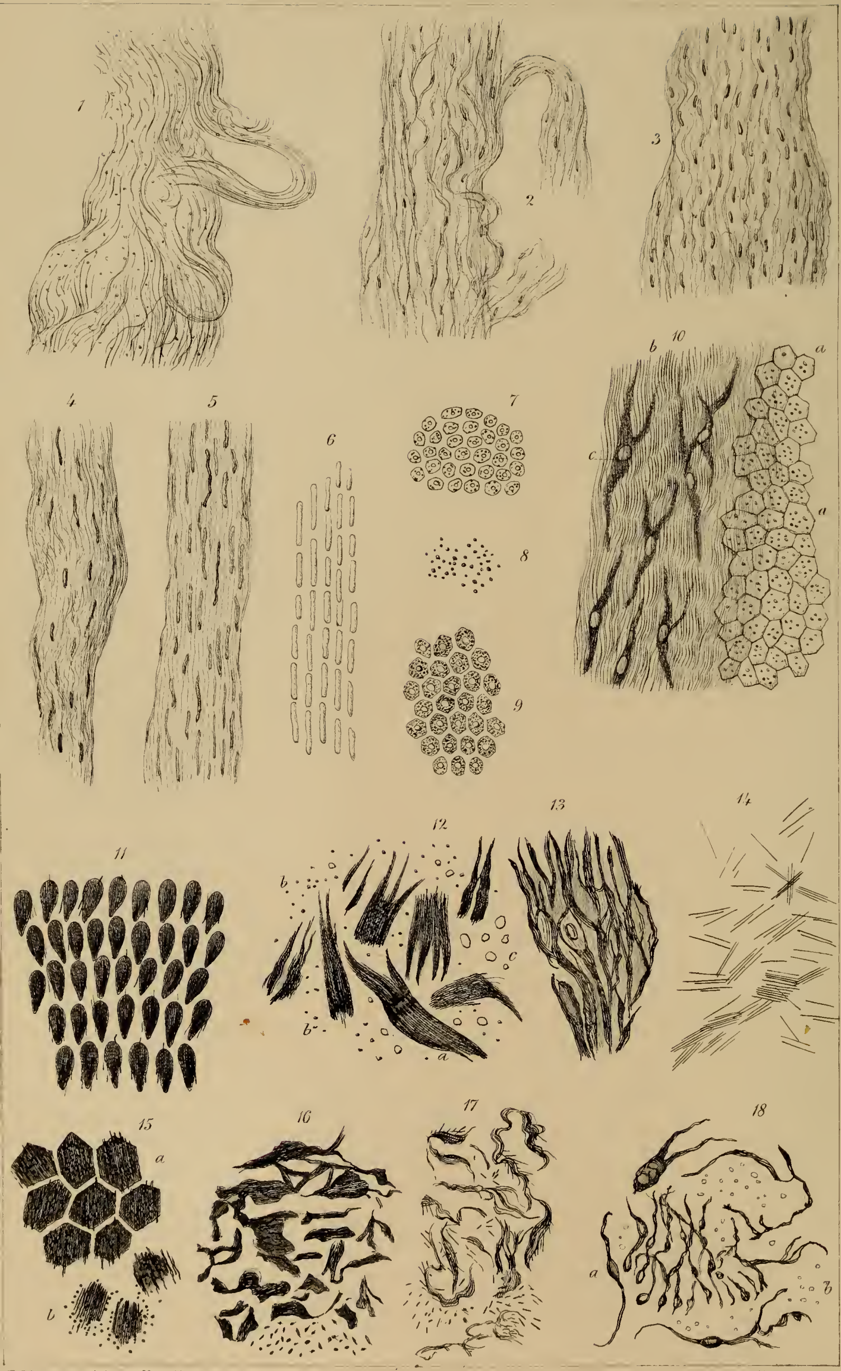
PLATE 2.



I. Nunneley del Tuffen West sc

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of and between the two, there is the attachment of iris with fibres of unstriated muscle running all round—*a* sclerotic, *b* middle layer of cornea, *c* portions of the elastic layer passing to iris, *d* attachment of iris; × 260.

Fig. 12. Cylindrical branched convoluted fibres, from the iris of fowl, just dead; × 260.

Fig. 13. Striated muscular fibre from iris and ciliary muscle of common fowl just dead, after addition of ammonia; × 260. N.B. In the text, page 178, it is stated I had not found the striæ in the ciliary muscle of birds: I have since distinctly seen it in several, but it is by no means easily to be seen in all birds.

Fig. 14. Pigment (uvea) from posterior surface of iris of sheep; × 450.

Fig. 15. Ciliary nerves in fowl. *a* while in ciliary muscle, *b* in the iris, where they soon lose the tubular character, and become very difficult to distinguish from the other tissues; × 450.

Fig. 16. Posterior half of left human eye seen from the front, fifteen hours after death, to show *a*, the slightly papillary projection of optic nerve: *b*, the branches of central artery of retina, and particularly *c*, the elongated elliptical folds of retina, which there enclose the black punctum centrale: natural size.

Fig. 17. Punctum centrale immediately after the removal of the eye; × 450.

Fig. 18. Layer of granulated cerebral cells of retina at punctum centrale; × 450.

Fig. 19. Section of retina through the puntum centrale after being some hours in Goatby's solution, to show, *a* the projection of the internal surface, with its central aperture, and *b* the depression on the outer surface; × 60.

PLATE II.

Fig. 1. Human ciliary unstriated muscle; × 450.

Fig. 2. Ciliary muscle from sheep just killed; × 450.

Fig. 3. Ciliary muscle after addition of acetic acid, by which the fibres are rendered less distinct, and the nuclei more so; × 450.

Fig. 4. Fibres from inner margin of iris of the horse in acetic acid; × 260.

Fig. 5. Fibres from the outer margin of the same iris, where they are not so numerous as at the inner, also in acetic acid; × 260.

Fig. 6. Elongated cells in ciliary muscle of eye of calf, seven weeks old, just killed; in acetic acid; × 260.

Fig. 7. Cells of choroid of a man, æt. 52, the choroid was very pale and contained hardly any pigment, but abundance of these nearly colourless nucleated cells of a slightly hexagonal form from pressure against each other; × 450.

Fig. 8. Minute cells into which the choroidal pigment in man and *every* animal I have examined is resolvable, all being of the same size, form, and character; × 450.

Fig. 9. Hexagonal choroid cells in the horse, from over the tapetum, where they contain very few colouring cells: by *transmitted* light, in which they form a most beautiful object; × 130.

Fig. 10. Portion of tapetum of ox, which is a most beautiful object in *reflected* light. It consists of nearly colourless hexagonal cells, under which is, *b*, very lustrous fibres, which reflect light like mother-of-pearl, and below these fibres *i. e.* to the outer surface are, *c* the stellate pigment cells; × 260.

Fig. 11. Dense black pyriform bodies—from inner surface of choroid of Cochin-cock, but which are alike in all fowls :—there is no central clear nucleus in them, and the bodies break up into the minute colouring cells; × 220.

Fig. 12. Pigment from inner surface of choroid of rook, which may be pulled out into pyriform feathery portions, as at *a*, which then separate into fibres and ultimately into the minute pigment cells *b*, *b*: amongst which may be found some clear larger cells, very like those of the retina, *c*; × 450.

Fig. 13. Same structure opened out after forty-eight hours' immersion in water; × 350.

Fig. 14. Silvery crystalline spiculæ, which form the anterior iridescent surface of the iris, and the outer white posterior surface of the choroid in fish, from the haddock; × 600.

Fig. 15. Inner surface of choroid of frog, just killed: *a*, dense black hexagonal cells; *b*, some of these separating into fibres, and then into the universal minute pigment cell; × 450.

Fig. 16. Outer white surface of choroid and anterior surface of iris, in the salmon; × 130.

Fig. 17. White *rete mucosum* near the operculum of same salmon, to show that the two are identical. In transmitted light (rather they will not transmit light) both are of a dense black; in reflected, of a beautiful metallic appearance, glistening like minute spiculæ of silver; × 130: both are splendid microscopic objects.

Fig. 18. Human choroid well teazed out with the hexagonal pigment removed, to show what is called the stellate pigment cells, which really consist of fibres and blood-vessels with the true pigment cells adhering to them; *a*, stellate cells, *b*, ultimate pigment cell; × 260.

PLATE III.

Fig. 1. The arteries of the choroid coat.

Fig. 2. The veins :—*vasa vorticosa*, of choroid coat.

Fig. 3. The ciliary nerves forming a complicated plexus in the ciliary muscle, and then passing on to the iris,—from a young man.

Fig. 4. The arteries of the ciliary muscle and iris from an infant.

Fig. 5. The blood-vessels of the choroid, ciliary muscle, and iris, seen from the external surface.

Fig. 6. Transverse section of anterior half of eye seen from behind; from a six months' fœtus; *a.* ora serrata; *b.* commencement of the ciliary processes; *c.* the processes themselves, having shorter foldings of the membrane between each larger; *d.* the central artery of the vitreous humor, which passes to the posterior capsule of the lens, where it divides into very numerous branches which, frequently inosculating with each other,

PLATE 3

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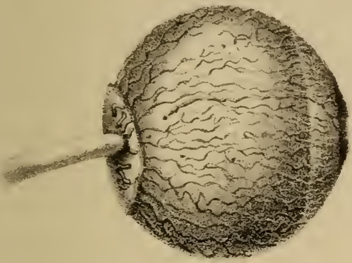

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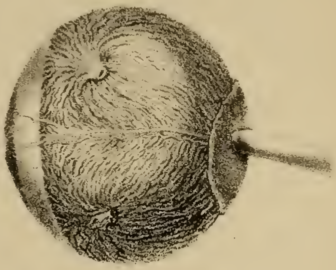

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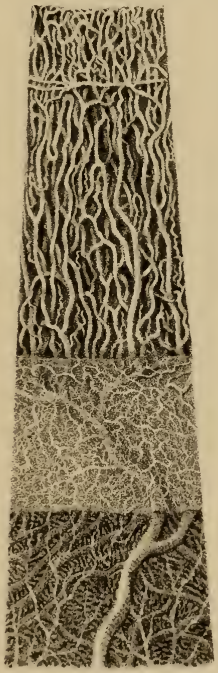

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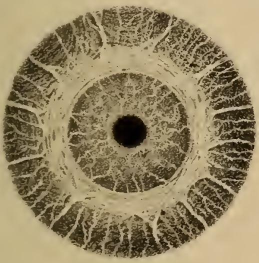

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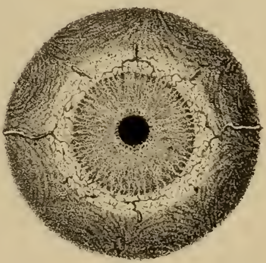

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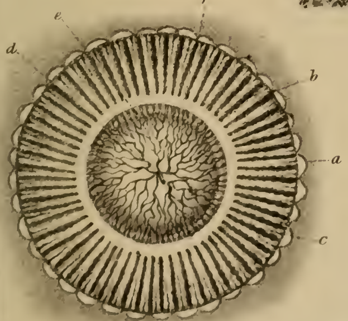

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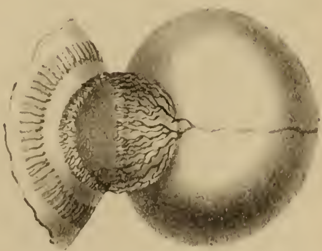

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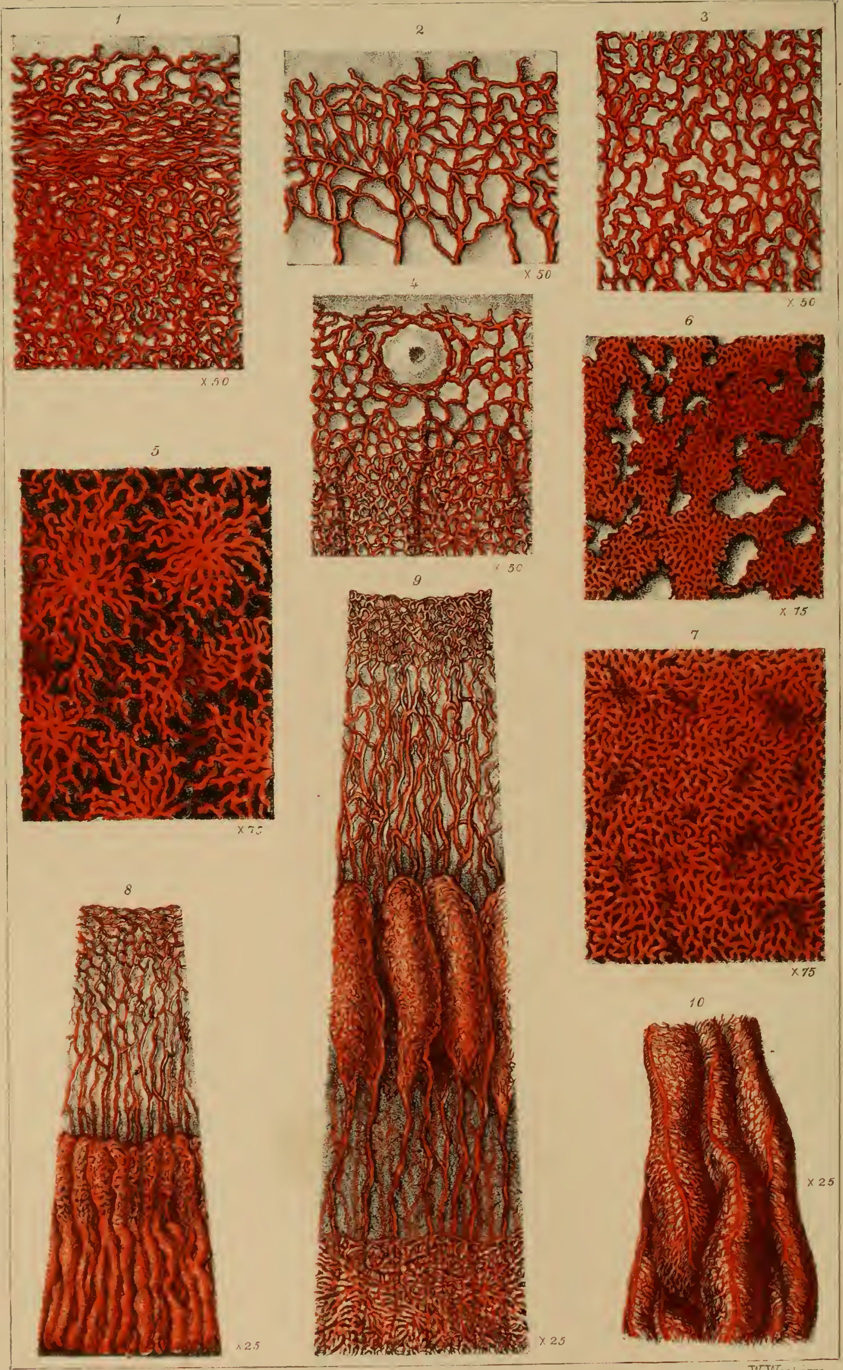
PLATE 4.



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W West imp.

PLATE 5.

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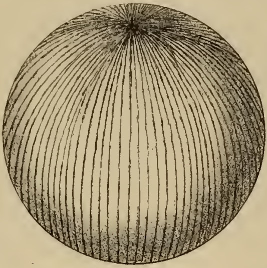

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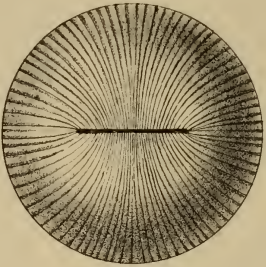

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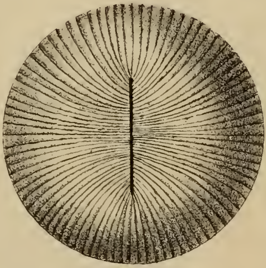

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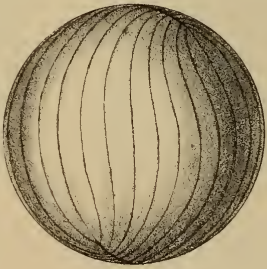

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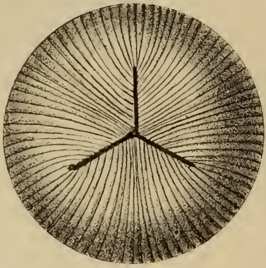

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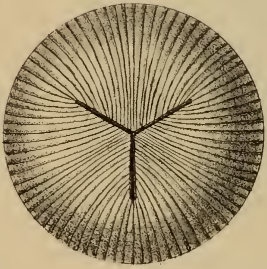

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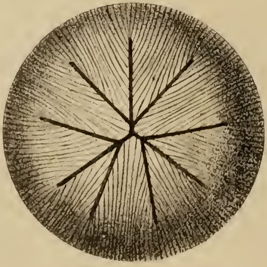

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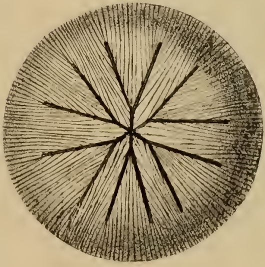
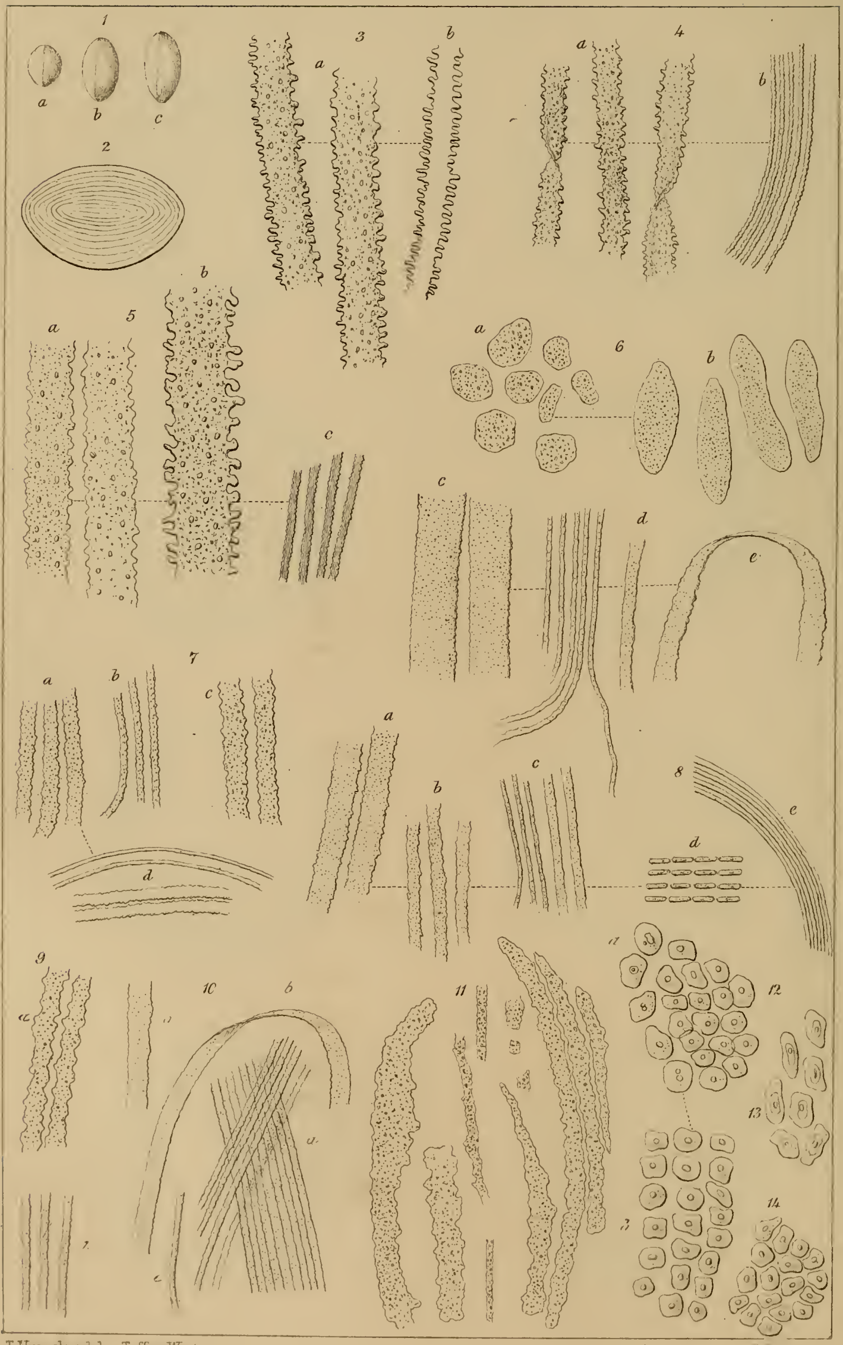


T Nunneley del. Tuffen West lith.

W West imp.

PLATE 6.



T. Nunneley del. Tuffen West sc.
W. West imp.

run on the outer surface of the capsule towards the edge of the lens, where they become nearly parallel and have a tendency to run in pairs opposite to each ciliary process round the edge of the capsule on to the anterior surface, where they are distributed, but do not form so free inosculations as on the posterior surface; *c*, margin of lens, which at this period is irregular, and does not extend to the edge of the capsule; *f*, at this period the lens is vascular, some branches may be seen passing from the artery of the capsule into it. It already divides into the three septa, and its individual fibres, though soft, are distinctly serrated.

Fig. 7. Eye in profile to show the passage through the vitreous humor of the artery, to the capsule of the lens—over which the inosculations are also seen to run; the choroid, ciliary processes, and iris are turned forward, and the vascular connection between the vessels of the iris and anterior capsule of the lens is seen.

Figs. 3, 4, 5, *and* 7, *are from Arnold;* 1, 2, *and* 3, *from my own preparations.*

PLATE IV.

Fig. 1. Conjunctival vessels, at junction of sclerotic and cornea injected rook; × 50.

Fig. 2. Vessels of conjunctiva at junction of sclerotic and cornea injected, cat; × 50.

Fig. 3. Palpebral conjunctival vessels injected, rook; × 50.

Fig. 4. Ditto, with opening of Meibomian gland, lamb; × 50.

Fig. 5. Inner surface of choroid of ox injected; × 75.

Fig. 6. Choroid and tapetum of lamb injected; × 75.

Fig. 7. Inner surface of choroid of pig injected; × 75.

Fig. 8. Ciliary processes and iris of pig twelve hours old injected; × 25.

Fig. 9. Vessels of choroid, ciliary processes, iris, and pupillary membrane injected, rook; × 25.

Fig. 10. Three folds of marsupium of rook injected; × 25.

PLATE V.

Fig. 1. Lens of cod, showing the fibres passing to one pole at each surface of lens.

Fig. 2. Lens of salmon, showing the fibres passing to two points on the anterior surface, and fig. 3 on the posterior surface.

Fig. 4. Perspective view of the course the fibres of a lens with two septa take in passing from one pole to the opposite.

Fig. 5 represents the anterior surface, and fig. 6, the posterior surface of the lens of a mammal having three septa at each pole.

These figures are from Brewster.

Fig. 7. Anterior surface of adult human lens, and fig. 8, posterior surface.

PLATE VI.

Fig. 1. *a*, lens of infant; *b*, of young adult; *c*, of old person.

Fig. 2. Enlarged lens, to show the different curves of its two surfaces and the arrangement of its layers of fibres.

Fig. 3. *a*, two fibres from the middle part (midway from margin and axis) of lens of haddock ; *b*, of cod, after being in boiling water and well dried, when the fibres are very clear and transparent ; × 450.

Fig. 4. *a*, three fibres from middle part of lens of frog. Two are shown completely twisted over, by which their flat riband-like form is well seen ; *b*, a group of fibres seen on the edge ; × 450.

Fig. 5. From turtle. *a*, two fibres from near the surface of the lens ; *b*, a fibre from the same layer in ether, to show the serrations more developed by this agent ; *c*, four fibres from near the axis, where many are almost cylindrical, and marked with longitudinal lines as though made up of smaller filaments ; × 450.

Fig. 6. From lens of a cock. *a*, cells filled with granules from quite the outer surface of lens close to the capsule ; *b*, other of these cells elongated, as though changing into fibres ; *c*, fibres from outer layers of lens ; *d*, fibres from near the axis of lens, nearly cylindrical, but some, as on right, are larger and flat, and at *e* a broad one is shown curved over ; × 450.

Fig. 7. Fibres from the lens of rat, squirrel, and hare. *a*, from middle ; *b*, from near axis of lens of rat ; *c*, from near outer part of lens of squirrel ; *d*, four fibres from middle of lens of hare, after coagulation and being dried ; two are seen flat, and two on edges ; × 450.

Fig. 8. From lens of ox. *a*, Fibres from near surface ; *b*, from near middle ; *c*, from near axis of lens ; *d*, bundle of fibres broken transversely from near middle of lens ; *e*, bundle of fibres seen edgeways ; × 450.

Fig. 9. From cat. *a*, two fibres from outer layer, showing how very irregular in outline they become from the effect of water at 212° F. ; *b*, fibres from near the middle of lens (midway between axis and margin) of other eye of same animal ; × 450.

Fig. 10. From human lens. *a*, fibre from outer layer seen on flat surface ; *b*, another fibre from same layer curved over ; *c*, fibre seen on its edge ; *d*, fibres from near the middle of lens ; × 450.

Fig. 11. Fibres from lens which had just been extracted from the eye of middle-aged woman, for fully developed hard cataract ; × 450.

Fig. 12. Epithelial cells from inner surface of capsule of lens. *a*, from anterior capsule ; *b*, from posterior, where I have found them arranged more or less in rows, so as to present a somewhat beaded appearance. From sheep ; × 450.

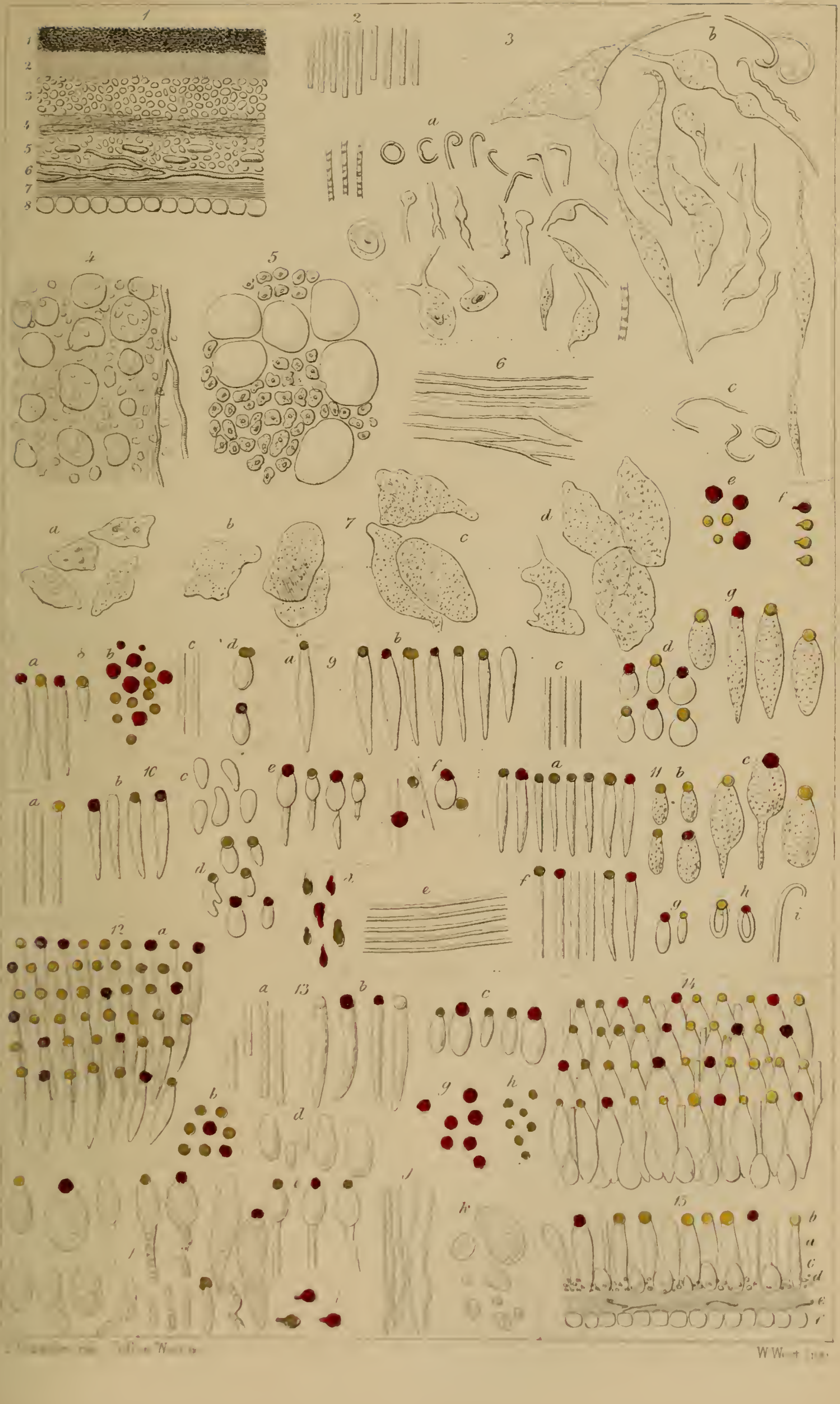
Fig. 13. Cells from inner surface of anterior wall of Petit's canal or suspensory ligament ; in some animals they are more or less oval, and contain a nucleus with nucleoli —from sheep. All these cells are rendered more distinct by acetic acid ; × 450.

Fig. 14. Cells from inner surface of capsule of lens of duck ; × 450.

PLATE VII.

Fig. 1. Vertical section of human retina, to show the relative position of its elements — (plan of). 1, choroid coat ; 2, rods ; 3, outer layer of granular cells ; 4, indistinct fibrous layer ; 5, inner layer of granular cells, in which are imbedded larger vesicular cells, and towards the inner surface is found, 6, the vascular layer, which consists of delicate vessels, derived from the larger branches of the central artery of retina ; these run on the inner surface of 7, which is the layer formed by the

PLATE 7



[illegible] del. Tuffen West sc.   W West imp.

fibres of the optic nerve; 8, transparent cells attaching the retina to the hyaloid membrane.

Fig. 2. Human rods; × 450.

Fig. 3. Rods in various stages of alteration. *a*, by the addition of water, or after the eye has been in dilute spirit, or a short time after death; *b*, after being treated with dilute chromic acid; *c*, after twenty-four hours' immersion in Goadby's solution; × 450.

Fig. 4. Inner surface of posterior portion of human retina, to show the granular layer with larger circular cells, amongst which the nerve-fibres run; to the left is seen an artery dividing into two branches; × 450.

Fig. 5. Same surface, with 1-12 object-glass, and achromatic condenser, × 600, without nerve-fibres, to show the clear transparent cells (probably enlarged by endosmose), and the cellular character of the so-called granular layer, which consists of true cells containing very refractive nuclei.

Fig. 6. Nerve-fibres from posterior part of human retina; they appear to bifurcate and to join each other again; × 450.

Fig. 7. Irregular flat cells found in the eyes of most, if not all, animals. *a*, from human fœtus; *b*, from pig; *c*, from sheep; *d*, from bullock: all just dead; × 450. Are they caudate gangliform cells?

Fig. 8. Turkey. *a*, conoidal rods surmounted by coloured globules; *b*, coloured globules of various sizes detached; *c*, cylindrical rods; *d*, ovoid bodies with coloured globules; × 450.

Fig. 9. Retina of birds. *a*, conoidal rod, with coloured globule, from canary bird; *b*, conoidal rods, with coloured globules, from various breeds of domestic fowls; in the same bird the size and exact shape varies, perhaps, at least to some extent, depending upon varying pressure against each other; *c*, cylindrical rods, not surmounted with coloured globules; *d*, ovoid bodies (bulbs, cones) with coloured globules; *e*, coloured globules seen on outer surface of retina as though with a nucleus, which they do not possess; *f*, coloured globules seen in profile, showing a small spur, by which possibly they adhere to the conoidal rods, though in the great majority this spur cannot be seen; they appear to be true globules; and I incline to think during life the spur does not exist; *g*, conoidal rods and ovoid bodies become granular.

Fig. 10. From duck. *a*, cylindrical rods, which are larger and more numerous than in the fowl; in one duck all the rods were cylindrical, and many of them were surmounted by the ruby and canary-coloured globules: there were none conoidal, except such as shown at *e*; *b*, conoidal rods from another duck; *c*, ovoid bodies without coloured globules; *d*, ovoid bodies with coloured globules; *e*, ovoid bodies with conoidal leg attached to the *inner* side; this process becomes detached and breaks up into discs, as do the cylinders, while the more globular portion becomes granular; so that it is difficult to say whether these are ovoid bodies with a portion of rod and globule accidentally attached, whether the ovoid bodies are not really altered conical rods deprived of the inner process, or whether the two forms are normal elements of the retina; *f*, cylindrical rods and ovoid body, with coloured globules accidentally attached; × 450.

Fig. 11. From swan and goose. *a*, conoidal rods with coloured globules; *b*, ovoid bodies with similar globules; *c*, three of the rods altered; *d*, coloured globules, fusiform in shape; *e*, strong cylindrical nerve-fibres in retina from swan; *f*, cylindrical and conoidal rods; *g*, ovoid bodies; *h*, rods curled round, so as closely to resemble ovoid bodies; *i*, rod curled into hook at one extremity; × 450.

Fig. 12. From Guinea fowl. *a*, outer surface of retina, with rods and globules *in situ; b*, coloured globules detached; × 450.

Fig. 13. From green turtle. *a*, long and short cylindrical rods, neither of which are very numerous; *b*, conoidal rods, for the most part surmounted with a coloured globule; *c*, ovoid bodies, surmounted with coloured globules; *d*, very nearly similar bodies, without coloured globules; *e*, ovoid bodies, with a short cylindrical leg attached at *inner* side, in two of them it is seen breaking off, they are surmounted by coloured globules; *f*, these different bodies after the lapse of a few hours, or immediately on the addition of water; and also from another turtle, which, before being killed, was in a very languid and feeble condition; *g*, average size of ruby globules; *h*, of canary globules; *i*, three of these globules in profile, to show spur which some appear to possess, but by far the greater number seem to be true globes, and probably during life are all so; when not exactly in focus, as the globules of birds, they appear to have a nucleus, which, however, they have not; *j*, nerve fibres forming a layer in retina; *k*, finely granular cells; × 450. In another turtle also, examined instantly the head was cut off, the coloured globules were much fewer in number, and not nearly so brilliant in colour; and many of the conoidal rods, *b*, soon divided transversely by an irregular line, the outer portion at once becoming granular, while the inner remained for some time transparent.

Fig. 14. Turtle; form, size, and position of elements of outer coat of retina, showing the cylindrical and conoidal rods with the coloured globules, and at their base the ovoid bodies; × 450.

Fig. 15. Section of retina of turtle. *a*, rods; *b*, coloured globules; *c*, ovoid bodies; *d*, granular cells; *e*, nerve-fibres and blood-vessels; *f*, transparent cells between last and the hyaloid surface; × 450.

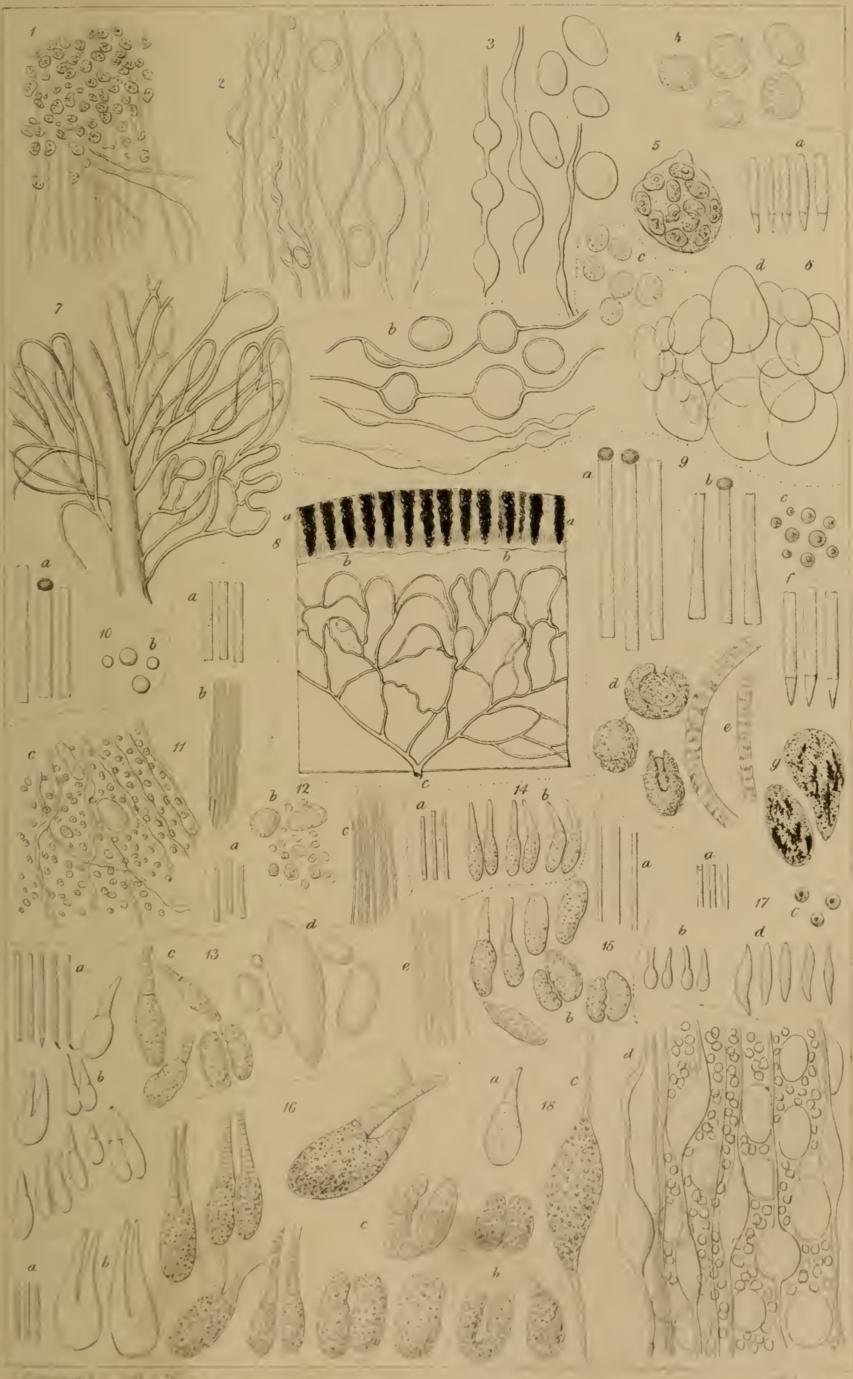
PLATE VIII.

Fig. 1. Portion of back part of retina of bullock seen from the inner surface, to show nerve-fibres and layer of granular cells, which have been partially removed the better to show the fibres forming a layer, with 1-12; × 600.

Fig. 2. Fibrous layer of retina, showing varicose enlargements in the nerve-fibres, and also double-walled cerebral cells; × 450; from back part of retina of rabbit. I have seen the same varicose structure in the pig, ox and sheep, but not quite so distinctly.

Fig. 3. Varicose fibres and clear oil-like cerebral cells from optic nerve in the pig, at its entrance into the eyeball.

Fig. 4. Layer of cells attaching retina to hyaloid membrane; at first they are perfectly transparent, but soon become very finely granular. They are found in most animals, and are very distinct in the rabbit.



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W. West imp.

Fig. 5. From turtle. There are a few large flat cells with large irregular granular nuclei; × 450. Are they the caudate gangliform cells? In two turtles I found these cells, but in a third I sought in vain for them, either therefore they do not exist in every eye, or they are a modified condition of other cells not always found, or they are so difficult of detection as to escape being seen.

Fig. 6. From birds. *a*, conoidal rods after some hours' immersion in dilute spirit, showing, towards the *inner* end, a conical process with a transverse mark as though breaking off here; *b*, nerve-fibres from anterior part of retina of Cochin cock; after being forty-eight hours in dilute spirit, they formed a complete layer imbedded in the granular cells; many of the fibres could be traced for a considerable distance, others were much shorter as though terminating at various points, all were more or less varicose; the dilations showed double walls, and with them were some double-walled cells; *c*, delicate cells, which are during life, or immediately after death become, minutely granular; they are very abundant in all birds; *d*, perfectly transparent cells, which soon become very large and irregular in size and shape, probably from pressure and overlapping each other; they appear to form a layer between the retina and hyaloid; these are from the canary bird; they are not larger in the goose or turkey than in this little bird; × 450.

Fig. 7. Capillary vessels of human retina; the artery from which they are given off measured 1-100 of an inch in diameter; the capillaries not more than 1-4000; washed with dilute liquor potassæ, which, by removing the nerve-structures, renders the congested vessels very distinct.

Fig. 8. Terminal vessels in human retina. They form a series of loops a little distance from the ora serrata. *a*, ciliary processes; *b*, loops of capillaries joining to form trunks, *c*.

Fig. 9. From frog. *a*, very large cylindrical rods; most, however, are of size seen at *b*; some of these are rather broader at their inner extremity than at the outer; many, but not all, are surmounted with a light-brown coloured globule, like those of birds and the turtle, but with much less colour; these are shown detached at *c*, they should not be shown with nuclei; *d* rods changed by the addition of water; they curl up, become granular, and look like coffee-berries; *e*, rods after addition of salt and water, which induces much less change than water; *f*, in one frog I found three rods with conical inner ends, and transverse marks as here shown, which I have also found in some of the rods in one turtle; *g*, a few large cells with pigment-granules, not much unlike some found in the brain, are seen; × 450.

Fig. 10. From toad. *a*, three rods; the majority are not as long as the longest; *b*, size of pale yellowish globules attached to some of the rods; × 450.

Fig. 11. From alligator; *a*, rods; *b*, fibrous layer of retina when fresh; *c*, same layer with granular cells after six hours' immersion in dilute spirit; the nerves have become varicose; × 450.

Fig. 12. From chameleon; *a*, rods; *b*, granular cells, with which are some larger brain cells; *c*, nerve fibres of retina; × 450.

Fig. 13. From golden carp, *Cyprinus auratus*; *a*, cylindrical rods; *b*, conoidal bodies, *cones jumeaux*, at first perfectly transparent; *c*, these same bodies after a short time, or immediately on the addition of water; the lower bulbous portion swells, becomes granular, irregular, splits in the middle, and forming the coffee-berry body, breaks up and disappears; while the surmounting conical leg breaks off, splits into discs, as do the cylindrical rods, and also disappears; *d*, ovoid cells of various sizes, of a dark fuscous colour; they resemble brain-cells; *e*, nerve fibres of retina; × 450.

Fig. 14. From sand-dab, *Platessa limanda*. In this fish the cones are not numerous, the rods and granular cells are far more so; *a*, rods; *b*, conoidal bodies; × 450.

Fig. 15. From little weaver, *Trichinus vipera*. In this fish the cones are very distinct, and far more numerous than in the last, but very few have the clear conical leg, and for the most part they lie singly and not in pairs as is common in fish; the rods are neither numerous nor well developed; *a*, rods; *b*, cones, which in this and the last fish, if not in life granular, become so before they can be examined; × 450.

Fig. 16. From whiting, *Merlangus valgaris*, which is a good fish for examination, the cones being well developed; *a*, small rods; *b*, cones with single bulbs and double conical legs, at first perfectly transparent and homogeneous, but in a very short time by immersion in dilute spirit, or instantly on the addition of water, the changes shown at *c* occur, and they disappear in granules; × 450.

Fig. 17. From eel; *a*, rods, which are numerous; *b*, cones, which are not so numerous; *c*, brownish-red transparent cells, in character not unlike the coloured globules of birds, except that they contain a nucleus; they are not more than half the size of the blood-globules, and they are circular; on the other hand they are much too large for the pigment cells of the choroid, which in colour they resemble; *d*, commencing change in rods or cones, which now (with 1-8) resemble, in size and form an oat corn; × 450.

Fig. 18. From cod, *Gadus morrhua*, where the retina is very thick and its elements simple; *a*, normal form and size of cone, the bulb is perfectly transparent and homogeneous; the conical process is single and has two transverse striæ, when it soon breaks; *b*, cones altered a few hours after death; *c*, a cone seen to alter while under examination, a large granular vesicle formed in the middle, and at each end was a long fibre; these subsequently swelled out, became granular, and disappeared; *d*, inner surface of retina, some hours after death, showing the large flat nerve-fibres become greatly varicose; they are imbedded in a layer of granular cells, with which are also found many large transparent cells; × 450.

CHAPTER I.

ON SENSATION, AND THE SENSES GENERALLY.

The senses are those special organs of animals and man which are so constructed as to be enabled to receive an impression from, and consequently to take cognizance of, objects extrinsic to the creature itself. Each of these organs of sense appears to be constructed in accordance with certain properties of those bodies upon which its functions are to be exercised, and by which, naturally (at least under most ordinary circumstances), they are alone excited into action; and thus, even when called into action by unnatural excitants, the sense gives no information of the nature of the unnatural excitant, but an idea of the presence of the natural quality or body is produced.

The senses are the means by which we obtain a consciousness of the individuality of our own bodies, and of the existence of a material world, distinct from ourselves. Without the presence of these organs of sense, we should have no knowledge of the external world, no appreciation of the present, no recollection of the past, no anticipation of the future,—neither idea of a Creator, nor aspiration for an hereafter. Nutrition, digestion, circulation, respiration, secretion, growth, and decay, the birth and death of the individual, the propagation and continuation of the species, might all go on as well as they do now; but there would be neither perception nor consciousness; the character of animals would cease to exist, only that of vegetables would remain.

In man, and all the higher animals, there are five of these special organizations :—Touch, Taste, Sight, Hearing, and Smell. Whether any creature exists which has more than the five we possess, or has an organ capable of appreciating qualities of bodies different from those man is enabled to take cognizance of, it is very difficult, if not impossible, absolutely to determine. There is no difficulty in affirming that many creatures do not possess all the senses that man does; for although it may be impossible accurately to point out the first commencement of any one of the senses in its earliest rudimentary form, yet the progressive changes in its development may be followed in an ascending and descending scale; while, on the one hand, we admire its most perfect condition, and are delighted with its elaborate construction, on the other all traces of its existence are gradually lost, until its very simplicity renders its possession doubtful. But though the form may be modified—be in the one creature simple, in the other complex—the same character and formation is found every where to prevail. We nowhere find other structures so different that they would lead to the supposition of being senses dissimilar to our own, or of being constructed for calling forth ideas with which we have nothing analogous. Nevertheless, it is possible such may exist; for since we have no other ideas than those which have been originally derived from our senses, together with their compound and complex ideas, it is obvious that did other creatures exist possessing another sense than our own, we should not have any conception of what this sense could be, what its structure or organization would be, what ideas it would suggest, or upon what qualities of bodies it could be exercised. Inasmuch as, if man had been born with only four senses, it would have been impossible for him to have had the ideas now derived from the fifth, so it is equally impossible for those possessing the five to conceive what a sixth sense could be. We can imagine modifications and extensions in the powers of our present senses; as, for instance, in that of sight, of having the faculty of seeing through opaque bodies, as we now do through transparent substances; or of hearing sounds to us now inaudible, which probably some creatures do; but these, obviously, are only ideas derived from senses already existing—a mere modification of powers we already possess, not a new and different sense dissimilar from anything we have ourselves or believe others to enjoy.

Dr. Thomas Brown and others have contended strenuously for the existence of a sixth sense, which they denominate the muscular sense; Brown, at considerable length, and with great ingenuity, maintaining that much of the information and many of the ideas generally supposed to be derived from the sense of touch are in reality obtained by this muscular sense, which he thinks quite distinct from that of touch. In this opinion many later writers agree; amongst others, Sir C. Bell and Dr. Abercrombie may be mentioned.* Notwithstanding the high authority of these writers, I would venture to think they are in error. This is not the place for entering at length into the question; I would therefore merely state that I think the supposition of a sixth or muscular sense has arisen from not sufficiently bearing in mind four facts. *First*, that the nerves of touch have no distinctive difference in structure or connexion from those of ordinary sensation; *secondly*, that nerves of ordinary sensation are distributed over all parts of the body, especially to the muscles, which, next to the skin, appear to be more liberally supplied with them than any other of the tissues of the body; *thirdly*, that no other nerves which, either from their structure, mode of distribution, or peculiar connexion with the sensorium, may reasonably be supposed to be endowed with other functions, can be detected passing into the muscles; and *lastly*, that ordinary sensation is sufficient to account for all the phenomena and ideas referred to the so-called muscular sense.

Hence, while it may be unhesitatingly affirmed that all creatures do not possess the whole of the five senses of man; some, very probably only one, and that in a very low degree of development, we can only say there is nothing whatever, either in the character, actions, or structure of animals, or, so far as we can perceive, in the nature of inanimate things, to justify the supposition of the existence, in any creature, of any additional or dissimilar sense, and, that though not absolutely impossible, it is in the highest degree improbable.

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* See Brown's "Lectures on the Philosophy of the Human Mind," Bell "on the Hand," and Abercrombie "on the Intellectual Powers."

Each of the five senses is essentially composed of a nerve or nerves, having an exterior termination in the form of a most delicate and complex membrane, or of beautifully minute and numerous filaments or loops expanded upon a membrane, and an interior termination in, or connexion with, the *sensorium commune,* either, as is the case with four of the senses, directly with the brain, or, as with the sense of touch, indirectly through the long nervous tract—the *medulla oblongata et spinalis.* However diversified we may find the habits of different animals, however modified the various special organs of sensation, however simple or complex they may be, however large and important or small and insignificant the central masses of the brain may be, it is curious to observe, and essential to a correct appreciation of the subject to bear in mind, that in all cases the careful observer may readily trace the same connexions and the same primary and essential parts. Wherever there is an organ of smell, there is not only an olfactory nerve, but the same tubercles of the brain with which the nerve is in communication. Wherever there is an eye, simple eye-dot though it be, there is a nerve and optic tubercles (*corpora quadrigemina,* or their analogues, the bigeminal bodies); wherever the one exists, there also are found the others.

In no instance is there any indication of a vicarious function being performed by any special organ, or a vicarious perception by any portion of the sensorium. Nay more, it would appear to be impossible that such should take place; for though many, and most dissimilar causes, will act upon the same organ of sense, and also the same cause will act upon different senses, yet we never find any variation or confusion in their effects, whether these causes are dependent upon some internal change in the brain, or in the organ itself, or upon some external application, either of a mechanical or chemical nature. Thus, disorder in the circulation of the head, concussion of the brain, the introduction into the blood of many poisonous agents, &c., all induce irregularity in the respective senses. A blow on the head makes the eyes to see light, the ears to ring; and so with the other senses and causes just mentioned. In fever, delirium, or inflammation of the brain (this is exceedingly well marked in *delirium tremens*), the patient sees strange sights and people, hears sounds and conversations, smells odours, and tastes flavours, feels heat and cold; all of which sensations arise only from his own disordered sensorium. So if the individual organ be disordered, the functions of that alone are perverted. An electric shock sent through the eye will produce a spark of fire, through the ear a sound, and through the tongue a saline taste; inflammation of the eyeball gives rise to a spark of fire, of the ear to troublesome sounds; mechanical violence, as a punctured wound, or chemical action, as caustic, induce the same perceptions; and however these excitants may be varied, the results are always the same. As light, according to its colour and intensity, may be pleasant or painful, hardly to be perceived or dazzling;—so sound may be harmonious or discordant, soothing and grateful, or harsh and offensive. Yet it is obvious these different feelings are only modifications of one sensation; the degree differs, but the nature of the sensation remains the same. Thus have we proof of the utter fallacy of the accounts of knavish or weak men and foolish women seeing by the pit of the stomach, hearing by the finger-ends, &c. There neither is nor can be transference of the senses; and clairvoyance, as it is absurdly called, is an impossibility. The senses may doubtless be each so excited and rendered unnaturally sensitive, that perception may be induced by an excitant so feeble that in an ordinary and healthy condition of things would fail to be perceived. Under these circumstances vision may occur in what to persons in an ordinary condition would appear a state of darkness, and sounds may be perceived from such slight vibrations as would be unheeded by the unimpassioned and normal auditory nerves of by-standers; but where there is *total* darkness, or an *absolute absence* of all sonorous vibratory undulations, where there is neither eye nor ear, optic nor auditory nerve, there will be neither sight nor hearing.

Besides this physiological reason, there is a difficulty of a purely physical character, of so formidable a nature, as in itself to show the impossibility of this transference of the senses, at least so far as the eye and vision are concerned. The eye is a dioptical instrument; an image of the object seen is formed upon the retina by the concentration of the rays of light as they pass through the cornea and crystalline lens. Without this image there would be no object seen, and without the lenses to refract the light, no image could be formed. Hence, even were there a retina or nerves similarly organized in any other parts of the body, as there is no dioptical apparatus there could be no vision. Even the eye itself would be useless if this refracting portion were removed, as the diagram will show. Supposing this to be a section of the sclerotic coat with the retina expanded within, but without the cornea and crystalline lens, it is obvious as the rays of light proceed in all directions from an object, they would fall upon *all* parts of the retina: the whole of this would be illuminated, but no image would be formed, and therefore there could be no perception of the object; it is possible light would be distinguished from darkness, but that is all; there could be no vision.

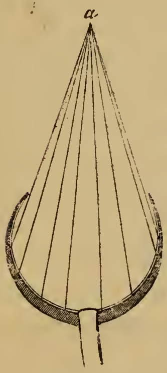

Fig. 1.

Not only do we find the different organs of sense modified according to the various qualities of bodies, which they are formed to take cognizance of, but we also find that they are more or less complex according to the manner in which they are to receive their impressions. Thus, when the impression is imprinted immediately upon the organ by the substance itself, the organ is found to be comparatively simple, as those of touch, taste, and smell; but where, as with the senses of sight and hearing, the organ is intended to receive impressions from distant objects through an intervening medium, not merely must we have the organ capable of perceiving the impression when this has actually reached it, but the organ must be constructed in exact accordance with the laws which govern the medium through which the impressions are destined to reach it.

Though we commonly speak of impressions being differently received by the different senses, in strictness this is probably incorrect; for there is much reason to suppose, that, as with the more simple senses, touch, taste, and smell, where everybody is sensible of the necessity for the object being immediately and directly applied to the nerve of sense, so with the more complex this is equally the case. In hearing, that which is really the object of sensation is not the distant sonorous body, but the undulations which actually strike upon the acoustic nerve spread out upon the membranous labyrinth. So in seeing, it is not the tangible and large distant landscape, but the very different and small picture thrown upon the retina itself, that is the immediate and only object of perception. To this I shall presently have more particularly to allude.

The complex apparatus added to these two nerves is for the purpose of bringing the impressions to them, the thing actually perceived being probably, in all cases, almost equally and directly applied to the percipient nerve. This explains why we have in the eye a most perfect dioptical instrument, and in the ear a beautiful acoustic apparatus. This it is which causes these two organs to be of so complicated a character, and accounts for the various and delicate modifications in their construction in different animals, and hence the modifications must be in accurate conformity with the laws which regulate the distribution of light, and the propagation of sound through different media.

In order to obtain an accurate and comprehensive knowledge of the physiology of the senses, with their respective uses and relative importance, it would be necessary to examine each one separately, and each might be conveniently considered under three heads.

1st. The ideas received through or by the sense,—the metaphysics of the sense it might be called.

2nd. With those organs of sense which receive their impressions from distant objects through media, we must become acquainted with, at least, some of the elementary laws which govern these media ; and, as has been said, in accordance with which the instrument of sense is constructed—the physics of the sense.

3rd. The structure or anatomy of the organ itself, and the phenomena observed during the exercise of its functions, must be carefully examined—the anatomy and physiology of the sense.

Were it my intention to investigate the structures and functions of all the senses, one of three different arrangements might be adopted.

1st. According to the respective importance of the senses to the animal.

2nd. Following the order of their appearance and extent of distribution amongst animals.

3rd. Commencing with the simplest organ, and proceeding upwards to the most complex of them.

The succession would then be, according to the *first arrangement,*

Touch, Taste, Hearing, Sight, and Smell.

To the second,

Touch, Taste, Sight, Hearing, and Smell.

To the third,

Touch, Smell, Taste, Hearing, and Sight.

To the first arrangement some objection probably might be made, and some explanation is necessary. For certain, the sense of taste to man is not of nearly the same importance as either that of sight or hearing; but to animals, especially to that vast number forming the great bulk of creatures, who are low in the scale of intelligence, the primary and essential thing is to eat and live. The sense of taste being that by which suitable food is selected, and noxious avoided, it is the preserver of the individual and of the species. So also, even with man, the relative importance of the possession of sight and hearing must be reversed, according to the age of the individual;—the entire and congenital absence of the organ of hearing being a greater calamity than the want of sight; while, undoubtedly, in adult life, the loss of sight is a far greater privation than the loss of hearing. This will be rendered more apparent after the remarks upon the ideas derived from the sense of sight are considered.

By some the second order might be also disputed, but, I think, after a pretty extensive examination of the subject, the order of the appearance of the senses is not very different from that enumerated.

So with regard to the third order, it may not unreasonably be doubted whether the organ of hearing be not as, if not more, complex than that of vision;—it possibly only appearing not so, because neither the structure and physiology of it have been so universally investigated by the anatomist as those of the eye, nor the laws of sound become so familiar to the mind as the complicated phenomena of light, which mathematicians in all ages have delighted to dwell upon. Though I hardly think the structure of the ear is so complicated as that of the eye; and its appendages, which are so numerous in the eye, are comparatively simple. The ear is imbedded in the cranium, and moved only as part of the whole head, whereas the eye enjoys an extensive motion, altogether independent of the socket in which it is lodged; the mechanism by which it is effected being more wonderful also, from the fact of each eye acting separately, and yet in perfect accordance with the other.

CHAPTER II.

ON THE FEELINGS AND IDEAS ASCRIBED TO, AND DERIVED FROM, THE SENSE OF VISION.

Reflective men in all ages have vied with each other in their admiration of the sense of sight. Nor is this to be wondered at, for whether we regard merely the mechanism of the organ itself, or the importance of the ideas derived from it, vision is certainly the noblest of the senses. Not only is the information obtained by it the most varied, important, and extensive, but it is also the most permanent and pleasing. Indeed, so frequently have philosophers and metaphysicians reasoned and speculated upon the sense; so often has the poet depicted its charms, and drawn his most beautiful imagery and illustrations from the gratification and ideas which it supplies, and which not unfrequently constitute the greatest attractiveness of his creative genius, as all—learned and unlearned—can feel and appreciate their beauty, richness, and appropriateness; and so completely in all languages have many phrases and expressions, which originally and in strictness belonged only to the sense of sight, been, and now constantly are, used in a much larger and more extended signification as applicable to all knowledge and mental power, that it is only after some thought and reflection, we perceive how commonly they enter into our every-day conversation and fireside talk.

Hence, perhaps, more care is requisite in analyzing the original and peculiar powers of this sense than may at first sight appear necessary.

The value of this sense has been so admirably stated by Dr. Reid and Dr. Brown, that I quote their words:—

“If we shall suppose an order of beings, endued with every human faculty but that of sight, how incredible would it appear to such beings, accustomed only to the slow information of touch, that, by the addition of an organ, consisting of a ball and socket an inch in diameter, they might be enabled, in an instant of time, without changing their place, to perceive the disposition of a whole army, or the order of a battle, the figure of a magnificent palace, or all the variety of a landscape; if a man were by feeling to find out the figure of the peak of Teneriffe, or even of St. Peter's Church, at Rome, it would be the work of a lifetime.

"It would appear still more incredible to such beings as we have supposed, if they were informed of the discoveries which may be made by this little organ in things far beyond the reach of any other sense. That by means of it we can find our way in the pathless ocean, that we can traverse the globe of the earth, determine its figure and dimensions, and delineate every region of it. Yea, that we can measure the planetary orbs, and make discoveries in the sphere of the fixed stars.

"Would it not appear still more astonishing to such beings if they should be further informed, that by means of this same organ, we can perceive the tempers and dispositions, the passions and affections of our fellow-creatures, even when they want most to conceal them? That, when the tongue is taught most artfully to lie and dissemble, the hypocrisy should appear in the countenance to a discerning eye? And that by this organ we can often perceive what is straight and what is crooked in the mind, as well as in the body? Surely he needs as strong a faith as is required of a good Christian.

"It is, therefore, not without reason that the faculty of seeing is looked upon not only as more noble than the other senses, but as having something in it of a nature superior to sensation. The evidence of reason is called *seeing;* not feeling, smelling, or tasting. Yea, we are wont to express the manner of the divine knowledge by seeing, as that kind of knowledge which is most perfect in us.

"If we should suppose it were as uncommon for men to see, as it is to be born blind, would not the few who had this rare gift appear as prophets and inspired teachers to the many? Would they believe that a ball, an inch in diameter, placed in a socket, and moved with muscles, could obtain all this information? Is it possible they could conceive the possibility of such an instrument?"*

"To open our eyes at present is not to have a simple feeling;—it is, as it were, to have *innumerable* feelings. The *colour*, the *magnitude*, the *figure*, the relative *positions* of bodies are seen by us at once. It is not a small expanse of light which we perceive, equal merely to the surface of the narrow expansion of the optic nerve. It is the universe itself. We are present with the stars, which beam upon us, at a distance that converts to nothing the whole wide diameter of the planetary system. It is as if the tie which binds us down to the globe in which we dwell, belonged only to our *other* senses, and has no influence over *this*, which, even in its union with the body, seems still to retain all the power, and unbounded freedom, of its celestial origin."†

According to the variety and importance of the information obtained by sight, and the incessant and constant use made of the organ, so do we find the loss of the sense felt as a most grievous calamity.

Let him, who from his full appreciation of, and enjoyment in, the delights of the sense, his almost inspired power, who from experiencing the total loss of it was more competent than any other person who ever lived to express the feelings attendant upon blindness, speak. For none but he could so feel and write. The quotations are long, but of surpassing beauty; and are the more applicable, inasmuch as they also illustrate the remark before made, as to the manner in which light and vision, with the ideas derived from the sense, are made to stand for all knowledge and reason. The whole of the glorious poem from which the latter extract is taken, abounds throughout with constant reference to sight, and the loss of it.

"Hail, holy Light! offspring of heaven first born,
Or of the Eternal co-eternal beam,
May I express thee unblamed? since God is light,
And never but in unapproached light
Dwelt from eternity; dwell then in thee,
Bright effluence of bright essence increate.

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* Reid's "Inquiry into the Human Mind."

† Brown's "Lectures on the Philosophy of the Human Mind," vol. ii. page 61.

Or hear'st thou rather pure ethereal stream,
Whose fountain who can tell? Before the sun,
Before the heavens thou wert, and at the voice
Of God, as with a mantle, didst invest
The rising world of waters dark and deep,
Won from the void and formless infinite.
Thee I revisit now with bolder wing,
Escaped the Stygian pool, though long detain'd
In that obscure sojourn; while in my flight
Through utter and through middle darkness borne,
With other notes than to the Orphean lyre,
I sung of Chaos and eternal Night;
Taught by the heavenly Muse to venture down
The dark ascent, and up to reascend,
Though hard and rare: thee I revisit safe,
And feel thy sovran vital lamp; but thou
Revisit'st not these eyes, that roll in vain
To find thy piercing ray, and find no dawn;
So thick a drop serene hath quench'd their orbs,
Or dim suffusion veil'd. Yet not the more
Cease I to wander where the Muses haunt
Clear spring, or shady grove, or sunny hill,
Smit with the love of sacred song; but chief
Thee, Sion, and the flowery brooks beneath,
That wash thy hallow'd feet, and warbling flow,
Nightly I visit; nor sometimes forget
Those other two equall'd with me in fate,
So were I equall'd with them in renown,
Blind Thamyris and blind Mæonides,
And Tiresias and Phineus, prophets old:
Then feed on thoughts, that voluntary move
Harmonious numbers; as the wakeful bird
Sings darkling, and in shadiest covert hid
Tunes her nocturnal note. Thus with the year
Seasons return, but not to me returns
Day, or the sweet approach of even or morn,
Or sight of vernal bloom, or summer's rose,
Or flocks, or herds, or human face divine;
But cloud instead, and ever-during dark
Surrounds me, from the cheerful ways of men
Cut off, and for the book of knowledge fair
Presented with a universal blank
Of nature's works, to me expunged and rased,
And wisdom at one entrance quite shut out.
So much the rather thou, celestial Light,
Shine inward, and the mind through all her powers
Irradiate; there plant eyes, all mist from thence
Purge and disperse, that I may see and tell
Of things invisible to mortal sight."

Paradise Lost, Book iii.

"But chief of all,
O loss of sight, of thee I most complain!
Blind among enemies, O worse than chains,
Dungeon, or beggary, or decrepit age!
Light, the prime work of God, to me is extinct,
And all her various objects of delight
Annull'd, which might in part my grief have eased.
Inferior to the vilest now become
Of man or worm; the vilest here excel me:
They creep, yet see; I, dark in light, exposed
To daily fraud, contempt, abuse, and wrong,
Within doors or without, still as a fool,
In power of others, never in my own;
Scarce half I seem to live, dead more than half.
O dark, dark, dark, amid the blaze of noon,
Irrecoverably dark, total eclipse
Without all hope of day!
O first-created Beam, and thou, great Word,
'Let there be light, and light was over all;'
Why am I thus bereaved thy prime decree?
The sun to me is dark
And silent as the moon,
When she deserts the night,
Hid in her vacant interlunar cave.
Since light so necessary is to life,
And almost life itself, if it be true
That light is in the soul,
She all in every part; why was the sight
To such a tender ball as the eye confined,
So obvious and so easy to be quench'd?
And not, as feeling, through all parts diffused,
That she might look at will through every pore?
Then had I not been thus exiled from light,
As in the land of darkness, yet in light,
To live a life half dead, a living death,
And buried; but, O yet more miserable!
Myself my sepulchre, a moving grave;
Buried, yet not exempt,
By privilege of death and burial,
From worst of other evils, pains and wrongs;
But made hereby obnoxious more
To all the miseries of life,
Life in captivity
Among inhuman foes."

Samson Agonistes.

The following beautiful passage from a drama, produced a few years ago, may also be not inappropriately added. The whole of the play, the plot of which turns upon the congenital blindness, and recovery of sight of Jolanthe, abounds with references to the faculty of sight, and also of touch :—

René, *addressing his daughter Jolanthe.*

"Then learn from me : there is a certain power,
Which men do call the light, like wind and storm ;
It doth descend upon us from above,
And like to these, with swiftness uncontroll'd,
The objects, which it touches, gain a new
Significance, and a peculiar stamp,
And oftentimes with warmth 'tis closely blent.
'Tis through the eye it finds its way to us
And by the power of seeing it we gain
A true perception of the universe
As it went forth from the Creator's hands,
And apprehend his wisdom and his goodness."

King René.

Though the importance of this sense has not been in the slightest degree exaggerated, and the loss of it is certainly the greatest bodily calamity which can befal a person, this statement must, however, be limited to an age after infancy, inasmuch as there is very little information that is obtained by the eye, which cannot also be obtained, and, in fact, *originally* is obtained by all persons, by the sense of touch alone. There is no doubt the blind can, and actually do, obtain as accurate a conception of space as those who see. The laws of optics, mathematics, astronomy, geometry, and all that relates to the measurement, distance, and form of bodies, are fully understood by the blind, as is proved by the fact of some of the most skilful mathematicians and calculators having been blind. Not that the blind man of himself could have discovered the nature and properties of light, or could have imagined any of the wonders and beauties with which the world and universe are filled. The sun might have warmed him, but of its character he could have no idea ; heat he could have felt,—but caloric, the cause of this sensation, would have been unknown to him. The moon that rules by night, the planets and the stars, and those other worlds and systems of worlds, for him would have no existence. The laws which regulate their motions could not have been conceived of. The revolutions of the earth ; the causes of the returning seasons, with their attendant seed-time and harvest, summer and winter, day and night, he might for ever have remained ignorant of; nay, his continued existence would have been very doubtful, if possible. But the presence and nature of light having been explained to him, the discoveries in astronomy having been revealed, the revolutions of the earth, moon, and planets having been demonstrated, the construction of the telescope, and the magic power of the microscope having been taught him by the medium of language, he can perfectly understand and fully investigate the principles by which they are all regulated, and may even improve the mechanism of the instruments employed.

With the single exception of the perception of colour, all the other functions of the eye may be, and indeed are exercised, by the sense of touch; and since the time of Bishop Berkeley, it has generally been thought proved, that by the eye we have not primarily any notion of magnitude, distance, or the real figure of objects, but that these powers of vision are the result of experience, being slowly and gradually acquired, which use has taught us to transfer from the sense of touch to that of sight. Indeed, Dr. Brown goes further than this, and maintains with great ingenuity that the original sensation of vision is that of colour *alone*, denying that the eye perceives extension at all. He declares that the visible figure does not involve the perception of length and breadth in the same manner as the tangible figure involves the perception of length, breadth, and thickness. Not that Dr. Brown denies the existence of the visible figure having length and breadth, which, indeed, cannot be done; but he maintains that it is not the dimensions of this visible figure which really and originally give rise, as a necessary effect, to the perception of the actual tangible dimensions; but that these are perceived from the variations in the colour and distinctness of outline of this visible figure. He contends, that, as there is no consciousness of the presence or size of the visible figure, and as this figure must vary very much in its dimensions according to the position and distance of the tangible object; that did our conception of the actual size of these depend upon the size of the picture of them thrown upon the retina, we should always, as a necessary consequence, connect the size of the former with that of the latter; and as the visible is larger or smaller, so should we consider the tangible to be, which is not the case. For in viewing the same object at a distance of a few yards, and at several hundred, we do not suppose the object in the latter case to be smaller than that in the former, but merely more distant. Whereas, according to Dr. Brown, were our perception of the dimensions of the tangible figure dependent upon the size of the visible figure, we should judge it not to be more distant, but smaller.

With the greatest deference to so high an authority, I conceive Dr. Brown here to be in error, and that the size of the visible figure is at least as important as the colour of it. We are as conscious of the presence of the visible figure as we are that there is a defined and bright or an indistinct and faint outline imprinted upon the retina. Both stand in the same relation and position as regards mental perception, our knowledge of the existence and variations in them being derived from observation, reflection, and experience alone; for there is no consciousness in the individual of the presence of either; and farther, it appears certain that it is only by experience the child learns, even with the variations in colour and outline, to estimate distance (as will be presently more particularly alluded to), there being nothing in the original perception to instantly give this knowledge of distance. Hence, as the size of the visible object varies in the same manner as the distinctness of the outline, both (*cæteris paribus*), being concerned, the size, brightness of colour, and distinctness of outline of the visible image increasing and diminishing equally and together, as the tangible object is near or remote, it appears to me to rest upon precisely the same foundation as the other does, both being necessary; experience and use alone enabling us to form a correct appreciation of the exact dimensions of the tangible figure from the visible figure.

Again, I would farther suggest whether Dr. Brown has not overlooked a most material difference in the structure of the senses, and of the manner in which the impressions are made upon them respectively, when he states, as in the following passage, that there is the same reason to suppose odours should give a knowledge of extension as that visible figures should do so. "But it will be said there is a certain figure of the part of the retina upon which the light falls. The fact is undeniable. But the question is not whether such figure exists, but whether the perception of the figure necessarily forms a part of the sensation. The brain and nervous system in general are of a certain form when they are affected in any manner. But it does not therefore follow, as the fact sufficiently shows, that the knowledge of this form constitutes any part of the changeful feeling of the moment. To confine ourselves, however, to the mere senses, it is not in the organ of *sight* only that the nervous matter is of a certain shape; it is expanded into some shape or other in every organ. When the whole or a part, therefore, of the *olfactory organ* is affected by the *rays of odour*, if I may so term them, we might, with exactly the same ground for our belief, suppose that the knowledge of a certain extension must accompany the *fragrance*, because a certain nervous expanse is, in this case, affected, as that the notion of a certain extension must, for the same reason, and for the same reason alone, accompany the sensation of colour. It is because the same light which acts upon the organ of one person may be made *visible* to another, that we conceive it more peculiarly to be figured, as it were, on the nervous expanse, when it is not in itself truly more figured than the number of co-existing particles of odour, which affect the nerve of smell. We cannot *exhibit* the particles of colour, however, acting on the nostril of any one. But when the eye is dissected from its orbit, we can show the image of a luminous body distinctly formed upon the retina. *We*, the observers of the dissected eye, have thus a clearer notion of the *length* and *breadth* of the nervous matter affected in the one case than in the other. But it is not in the dissected eye that vision takes place, and as the living eye and the living nostrils are alike affected in more than one physical point, we must surely admit that in *both* cases, and in both cases *equally*, a certain *length and breadth* are effected, and that there is an *olfactory figure* as truly as a *visible figure*. The visibility of the image to another person cannot alter the nature of the organic affection itself to the *sentient* individual. If the olfactory figure be not necessarily accompanied with the perception of extension, there is no stronger reason, *à priori*, to suppose that what is termed the *visible figure*—which is nothing more than a similar affection of a nervous expanse—should be accompanied with the knowledge of the part *of the retina affected.*"[*]

Upon this statement I would remark that in reality there is such a difference in the structure of the two senses as to convert Dr. Brown's statement into an argument against himself. It is perfectly true there is a certain form and expansion of the olfactory nerve in the nostril as well as of the optic in the ball of the eye; in the latter organ there is an apparatus most accurately to concentrate the varied forms and figures of the impression upon one part alone of the nerve, but in the former no such apparatus exists. Odours of all kinds, from all distances, whether intense or feeble, are expanded over the whole membrane of the nostrils; therefore, as far as figure or extension goes, they produce the same, or rather no effect, as might *à priori* be supposed. They vary in intensity, and according to their degree of intensity, do they impress the olfactory nerve, and are perceived to be strong or feeble; but, as they are not impressed upon one portion of the nerve alone, they do not give rise to the perception of form or figure: no variation in shape can possibly occur, but in intensity only, which does happen. Not so in the eye. In it a definite figure is necessarily impressed upon one portion of the retina alone by the dioptical apparatus placed anterior to it. This figure varies in size, position, and shape, as well as in the intensity of light and distinctness of outline; so that we have, as we might from this fact, I think, fairly expect, not merely a perception of distinctness or indistinctness, as in odours, but also of size and shape.

Upon the whole olfactory expanse all odours are equally diffused, whether they be concentrated or diluted; hence, the whole surface being in every case affected, merely a perception of intensity or weakness can arise; whereas, the rays proceeding from a tangible object are collected together, and thrown in a definite form and colour upon one portion alone of the optic expanse, and as this portion varies, so does the perception.

In order to understand how it is that the information which we, in adult age, are accustomed to gain at a glance originally belongs to touch, it is necessary to fix the attention upon the fact that it is not the real and the tangible object itself which we see, but only the image of it, which is thrown, by the convergence of the rays of light, upon the bottom of the eye; so that we may be said in reality to see by touch, inasmuch as it is the visible object actually impressed upon the retina which we see. This admits of an easy proof. From whatever distance the rays of light come, whether from an object held in a person's own hand or from a distant star, it is obvious that at the moment of vision the rays must be equally near to the eye. So also, the tangible object remaining exactly the same, we may alter the appearance of it by interposing concave or convex glasses, or the colour of it by viewing it through stained glass, or the number, as, by employing the ordinary multiplying glass, a dozen or score objects may be seen when our sense of touch assures us only one exists. So also, a plain surface, having only two dimensions, may be so coloured and shaded as to represent to the eye a cube or sphere, with its triple dimensions, as accurately as the object itself could do. It is in correctly understanding and carefully representing the exact correspondence of these double and triple dimensions, in their various relations to the eye, that the whole art of perspective consists.

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[*] Brown's Lectures, &c., vol. ii. p. 92.

If this be true, how then is explained the manner in which a minute and superficial picture, having only two dimensions, which it may be said is in contact with the retina, should call up the immediate perception of distance, projection, and magnitude in the objects we look upon?

This is the result of experience. It is only gradually and slowly acquired during infancy.

The means by which a knowledge of the distance of objects is acquired, are usually considered to be dependent upon three circumstances:—

1st. Upon differences in the affection of the retina itself.

2nd. Upon different movements in the muscles by which the eyes are moved.

3rd. Upon our previous knowledge of the size and distance of other objects, which form part, as it were, in one compound perception.

To these means I should venture to add, as, though commonly overlooked, not without importance, three others.

4th. Upon differences in the condition of the iris, or diaphragm of the eye.

5th. Upon changes in the focal length of the eyeball itself, or of some parts of it.

6th. Upon, as Mr. Wheatstone maintains, a *different picture* of the object being formed in *each* eye. A consideration of this will be deferred until the physiology of vision is considered. See Chapter vii.

1st. The difference in the image upon the retina will be of a twofold character; the one relates to the size of the figure, the other to the distinctness and strength of outline and colour. The visible figure is greater or less, according to the greater or less distance of the tangible object from the eye, the same object throwing a larger image upon the retina in proportion to its nearness to the eye. To this, as I have before mentioned, Dr. Brown is not inclined to attach much importance, but to which Dr. Reid and most others do. I have already stated my reason for agreeing with them. The second difference in the condition of the retina depends upon the greater or less intensity of the light, and the sharpness or indistinctness of the outline. It is obvious the nearer an object be to the eye, the greater will be the number of the rays of light from it which will enter the eye, and consequently the lighter will be the colour, and the sharper the outline; while, on the contrary, the more distant the object, so will the rays of light be fewer, and, as a consequence, the dimmer will be the colour, and the more indistinct will be the outline of the object upon the retina.

That painter who most exactly understands and most skilfully represents these differences will be the best artist. In fact, upon this (*cæteris paribus*) the magical skill of the painter depends. The same object, at different distances, is in reality to the eye a different object; for its visible figure is of neither the same form nor colour. The uninformed person and the unskilful painter, not knowing this, or not being able to represent the different effects, is unable to produce a picture which is pleasing, or which deceives the imagination into the supposition of its reality, the outline and colour of near and distant objects being represented too much alike. Accordingly, his picture appears nearly the same, whether viewed from a near or a distant point. Not so that of the accomplished artist. His landscape, viewed too near, presents only a confused and unintelligible daub of indistinct outline, and a partially mixed-up mass of various colours; but regarded at a proper distance from the canvas, the eye is charmed, the mind delighted, and the imagination cheated into the belief of the reality of a widely-extended landscape of sky and water, of rock and field, of flood and fell, lonely and grand,—or sunny and luxuriant, teeming with life and animation.

By his different shades of colour the painter produces corresponding perceptions of distance; and thus, by differently shading the parts of a *plane* surface, which we know must be equally near to the eye, converts them, so far as the eye can judge, into very various objects, as a rough block of stone or a magnificent temple. By the indistinctness of outline which is given to the small figures placed in the back-ground of the picture, the painter leads us to suppose these figures not as smaller, which we should do were the outline sharp and distinct and the colour bright, but merely as more remote than those figures which are so distinctly painted. Thus, by making his figures larger or smaller, more or less bright in colour, and sharp in outline, the artist, upon a small space of canvas, can present us with a landscape of miles in extent.

The intensity of light and the clearness of colour of objects decrease according to their distance; so that objects always appear less bright and more tinged with the colour of the medium through which they are seen the further they are removed from our eyes. So that, if we know two objects are of the same colour, and one be brighter than the other, we at once conclude that this is nearer to the eye than the less bright. Hence it is that all bodies, when they are strongly illuminated, appear nearer than they really are; and when less illuminated, they appear larger and more distant than they really are. This is one reason (another will be given presently) why the sun, moon, and stars, appear larger when near the horizon than when in the clear air above head; for as there is a larger tract of thick moisture and vapour for the rays to pass through in the horizontal line than in the vertical, and consequently more rays of light are absorbed by it, these bodies are less brilliant, and thus appearing more distant, are also judged to be larger.

Of the same nature as this is the error into which we fall when the usual character of the medium in which we are accustomed to view objects is changed. When the condition of the light is altered, our judgment of the position and size of objects is not at all to be depended upon. If the atmosphere be unusually clear and transparent, all objects appear to be much nearer than they usually are. Hence it is that in an atmosphere clearer than our own, all travellers remark the different effects objects produce. They are seen at a much greater distance, and appear to be much nearer than they really are. Berkely, if not the first to remark this while travelling in Italy, was the first to give a satisfactory explanation of the cause. For the same reason, when the atmosphere is unusually thick and dense, all objects appear to be larger than they really are, because their outline and colour are as indistinct and dim as those of larger and more distant objects in an ordinary condition of the air. With this everybody is familiar, and is aware how magnified well-known objects appear in a fog; and also how, as the shades of evening creep on, when travelling in a new country, all objects which we are approaching appear formidable; their outline is indistinct; they appear larger and more distant than in the daylight; a small and very harmless animal may in a foggy night be easily converted into a fearful and unknown monster. This is doubtless the solution of many a good ghost and goblin tale of benighted travellers, whose truthfulness in the belief of the reality of what they encountered may be saved at the expense of their philosophy.

2nd. The second means by which we estimate distance is by the action of those muscles which move the eyes. As we are able to see distinctly at distances varying from a few inches from the eyes to many yards, it is obvious the direction of the axes of the eyes must vary, and, as we have the power of varying and changing the direction of the eyes, so as accurately to follow a moving body, whether its motions be slow or rapid, there must originally, if not at all subsequent times, have been the consciousness of this direction. Now, all that can possibly be required, is that the mind should be capable of estimating and remembering the different feelings of muscular exertion which are required at different distances, and that it should, by the power of association, be able to connect them with those distances otherwise ascertained.

But I might go farther than this, and ask if it be necessary in this process that there should be consciousness and perception of the change at all? Is it not possible that the movements should be automatic and yet precise? Are not many movements of far more essential importance in the constant maintenance of life of this character? Closely connected with this subject are those of the change in the condition of the pupil when regarding objects at different distances, and the adjustment of the eye to correcting the aberration of parallax. To both of these we shall presently have to refer, and to the latter of the two inquiries, which is one of the most important as well as one of the most interesting and disputed questions connected with vision, at greater length when treating of the physiology of vision. But whether automatic or the effect of consciousness and volition, certain it is that the axes of the eyes do vary according to the different distances of objects from them; and therefore we may fairly presume the variations must have some influence in enabling us to estimate these differences; and that, in point of fact, we do so judge of distance, every one may readily satisfy himself by closing one eye and attempting to snuff a candle, thread a needle, or to touch any small object within a short distance of himself, when he will find that he will frequently fail in doing it from not correctly estimating the distance. Though, inasmuch as persons who have for some time lost one eye have also the power of estimating the size or distance of objects (though never, I think, with altogether the same precision as those persons who possess both the organs), this means of measurement must not be considered as absolutely essential in our estimate of distance, though unquestionably in ordinary circumstances of great value when the object is within a certain moderate distance; for at all great distances, where the space between our two eyes bears no sensible proportion to the distance of the object looked at, we are deprived of this means of estimating distance, and hence our difficulty of estimating distance of objects increases as they are farther from us, until the axes of the eyes become parallel, when our estimate of size and distance is not in the least to be depended upon, unless either the one or the other of them is previously known to us, when we judge of the one from our knowledge of the other; or there be other things so situated that we can compare and thus form our estimate. What the exact distance is at which the visual angle becomes insensible it is very difficult precisely to determine; it has been calculated at 120 feet, beyond which distance De Charles declares we judge of size and distance not by sight alone, but by the assistance of reason as well, and he gives this as the reason why the sun appears to be only about a foot in diameter, being seen under an angle of about 30″; a circle of a foot in diameter at the distance of 120 feet from the eye being also seen at an angle of 30″, and hence the two appear to be equal in size.

3rd. A very important help to the correct appreciation of the distance of an object is our possessing a previous knowledge of the country in which we are placed; this must be familiar to every person. We are all conscious of how much more correctly we judge of the size and distance of a moving object in a locality which we well know than in a district to which we are strange. In this latter we are unable to make the comparison between objects well known and the one we are observing, consequently we have not the accustomed means of calculating the distance of it. If the country be full of objects we are in danger of over-estimating the distance; while, on the contrary, if there be few or no objects intervening between our eyes and the object observed, as across a broad river, upon a large tract of moorland, a bare sand-field, or watching a distant vessel upon the sea, the distance of objects is almost invariably under-estimated, there being none of those intermediate objects by which the eye is, under ordinary circumstances, guided. All know how much more correctly a seaman can estimate the exact distance and size of a far-off vessel than the uninitiated inquirer; whereas in observing the objects in a landscape the landsman has the advantage, each being guided by experience. In the former case, the landsman will most likely under-estimate the size and distance of the vessel; while in the latter, the seaman will fall into the opposite mistake.

All of us, when approaching a city, castle, or mountain larger than we have been accustomed to see, suppose them to be nearer than they really are; because, experience having taught us that similar things of which we know the size, present, at a certain known distance, a certain appearance which is familiar to us, and as the apparent magnitude of the larger objects at a greater distance is the same as that of the smaller at a smaller distance, it suggests to the mind the familiar idea of the smaller object at a less distance, and not of the larger at the greater distance. This is the reason why most travellers, on first approaching the Alps, and similar mountains, are at first not so impressed with their size as subsequently, when experience has taught the great distance at which they are visible, and having also ascertained the time taken in climbing over them. It may not improperly be mentioned that precisely similar is the explanation to be given of the appearance of the form of the vault of heaven, which does not seem to be a portion of a sphere, but a segment of a far larger sphere. Along the horizon there are countless objects, whereas in the line of altitude nothing intervenes, hence the flattened form which the arch always assumes.

So, also, the sun and moon appear to be larger when near to the horizon than when elevated high in the heavens, because, in the first position, we judge them to be more distant in consequence of other objects intervening, so that the same visual image leads to the idea of the tangible object being larger or more distant than when there are no intervening objects; and hence, if these luminaries are viewed through a long tube when in a horizontal position, from the exclusion of intervening objects, the apparent distance vanishes, and with it the apparent magnitude deduced from it.

4th. Very little attention has been given to changes in the size of the aperture of the pupil as a means of guiding us in the estimation of the distance of objects; yet nothing is more constant. In regarding near objects the pupillary aperture is always contracted, and (*cæteris paribus*) when distant objects are looked upon, dilated. This uniformly takes place, the degree of light being the same, and may easily be seen by any one attentively observing the eye of another person, who, after examining a near object, successively directs the eye to others which are more and more distant, when the pupil is perceived gradually to become larger. On the contrary, when the eye is withdrawn from the distant prospect to be fixed upon an object within a few inches of the face, the pupil at the same time diminishes in size. The optical reasons for these changes will be explained hereafter ; all that is desired at present is to call attention to the uniformity of this change. This change in the pupil was dwelt upon by De la Hire, Poterfield, and others of the last century, but there has, by some of the more recent writers, been an omission of due notice of it, which has probably arisen from most of them having been rather metaphysicians than physiologists, as well as from our not being conscious of these changes in the size of the pupil, and their not being under the control of the will—at least in man—for which reason some may also not be indisposed to deny their assistance in our estimate of distance. I do not, however, consider it is necessary in all cases where changes take place in the body, that these changes should directly be the effect of volition, or even attended with consciousness. A number of movements are constantly taking place in the body, upon which most essential functions are dependent, which, if not of a purely automatic character, are certainly not voluntary, nor accompanied with consciousness. Many of these movements occur during the process of digestion, circulation, and respiration. But I may refer to that change in the eye itself, which all allow to be one of the most important means of our estimating distance, viz., affections of the retina. It is admitted by every one that according to the brightness or dimness, the distinctness or indistinctness of the visible figure, so do we judge of the position and distance of the tangible, and yet what consciousness or volition is exercised in these variations? Not only is the mind unconscious of these variations, but it is, in point of fact, unaware of the existence of the figure itself, much less of differences in it. Hence, if the one be allowed to form an element in our estimate of distance, I do not see why the other may not also.

5th. Accompanying the change in the size of the pupil (and it must be still more so if from any increase or diminution in the intensity of the light the usual actions of the iris do not occur and distinct vision remains), the refractive powers of the eye vary, or the distance between the purely optical part of the eye and the retina change, according to the greater or less divergence of the rays of light coming from the object to the eye. The aberration of parallax, and the means by which it is overcome, will demand attention hereafter; but that such changes do occur is certain, and I know of no valid reason why they, as well as degrees of light, may not also be concerned in our estimate of distance; indeed, so far as consciousness and volition are involved, it is in favour of the latter; for I think every person, when attentively examining a small object, placed near to the eye, is aware of an effort, and is also conscious of being capable, by an act of volition, of increasing or diminishing the strain; and if this consciousness be not always present, it is probably only because the effort is less, and consequently is not perceived or not attended to, habit and constant repetition having their usual effect of weakening the mental impression.

Within ordinary limits, our estimate of the distance of objects is made so suddenly, and, as it were, intuitively, or as a necessary consequence, from an original faculty of perception belonging to the eye, that the mind is not at all conscious of the process; and, when made, the impression is so strong, that no present knowledge will overturn it. This is the explanation of a fact with which every one is familiar. When a distant object is viewed through a telescope, the brightness of the colouring, the sharpness of outline, and the magnitude of its image being such as belong to a near object, no effort of the will can overcome the delusive perception, which, in consequence of established habit, gives rise to the idea of its being a near object. We may correct this error by our previous knowledge, but not by the eye alone. It is the effect of experience, and not of sight. There was, therefore, nothing to wonder at in the countryman who for the first time in his life, on looking through a large telescope, went to the other end of it to examine the distant object he had just seen through the instrument, nor his incredulity, when told the indefinite spot was the same object miles away, for he had just seen a near and distinct object.

When we look upon an extended landscape, we behold a vast variety of objects, many of them of immense magnitude, yet all these are really brought to the eye in the smallest dimensions imaginable. This has been admirably stated by Dr. Smith, who says:—"It is because almost our whole attention is employed, not upon the visible and representing, but upon the tangible and represented objects, that in our imagination we are apt to ascribe to the former a degree of magnitude which does not belong to them, but which belongs altogether to the latter. If," he continues, "you shut one eye and hold immediately before the other a small circle of plain glass of not more than half an inch in diameter, you may see through that circle the most extensive prospects—lawns, woods, and arms of the sea, and distant mountains. You are apt to imagine the landscape which is thus presented to you, that the visible picture which you thus behold, is immensely great and extensive. The tangible objects which this visible picture represents are undoubtedly so; but the visible picture which represents them can be no greater than the little visible circle through which you see it. If while you are looking through this circle you could conceive a fairy hand and a fairy pencil to come between your eye and the glass, that pencil could delineate upon that little glass the outline of all those extensive lawns, and woods, and arms of the sea, and distant mountains, in the full and exact dimensions with which they are really seen by the eye."

From this comparatively short and imperfect account of the qualities of bodies upon which sight primarily is exercised, it is evident that in infancy they are few, and cannot be put in competition with those of touch, with which they are so generally confounded. The perceptions of touch and sight are, it is true, in after life in many respects identical, but in the case of vision, the faculty has, so to speak, to be learnt by a slow and gradual process during earliest childhood; and, doubtless, could we have fully unfolded to us what is taking place in the sensorium of the infant, this would become at once evident. As, however, this is impossible, we must be content to watch attentively and observe carefully the infant as its strength and powers are gradually developed. Follow the child from birth through the first six or eight months of life, and observe at first there is only the mere perception of light from darkness; soon bright colours and shining objects are perceived; afterwards some consciousness of the form of these; then many feeble and unavailing efforts to direct the hand to them are made, obviously without any knowledge of the distance of them, until increasing strength and experience, with the better development of the sense of touch, gradually enables the little creature to estimate with some degree of correctness the size, form, and distance of different objects. Let any intelligent and watchful mother who has her attention directed to this subject, answer if the unfolding powers of vision in her infant are not as now stated.

But we are not absolutely reduced to this process of observation and analysis as our only means of determining this question; for it has occasionally happened, that persons have been allowed, and still are, to grow up to manhood, or to an age sufficiently advanced to have all their mental and corporeal faculties developed, who are endowed with all the senses but that of sight, and who are suddenly made to see, and who, consequently, can directly inform us of their newly-acquired sensations.

It will readily be understood that I refer to those cases of congenital cataract which have been neglected in early life. One of the earliest cases, and, in many respects, most remarkable, is that of the young man operated upon by Cheselden, which has been referred to by nearly every subsequent writer on metaphysics in terms of great satisfaction, as it by direct and unexceptionable experiment confirmed the deductions which had previously been arrived at by the most careful and laborious investigations into the functions of the different senses, and an analysis of the ideas received by them. The account of this operation, and the acquisition of sight from it, was published by Cheselden in the Transactions of the Royal Society. Sir Everard Home, and others, have published confirmatory cases, so that no doubt can remain of the general truth of the statement. I would, however, remark, that by more than one writer have these cases been overstated, and more said than either the original account by Cheselden or exact truth will bear out. It has too frequently been assumed, that previous to the operation there has been *complete* blindness, and after it perfect vision. Now the fact is, that as before the operation in these cases, there is not total blindness, so after it the eye is not nearly so perfect as it is in those persons who have not had any original defect; neither is the acquisition of sight altogether sudden, but progressive; nor can any observations be safely made immediately after the operation. So that, although the cases are sufficiently satisfactory for all practical purposes in the inquiry, they are not altogether so decisive as has sometimes been stated. Perhaps, as one which fell under my own notice, some years ago, is as conclusive, if not more so, as any that are on record, I may relate it, especially as both before and subsequent to the operation, I took every precaution in the endeavour to make accurate observations.

The case was that of a fine and most intelligent boy, nine years of age, who had congenital cataract of both eyes, in whom the retina was more perfect than it commonly is at so advanced an age, as shown by the excellent sight he subsequently acquired. He had always lived in a very large manufacturing village, about sixteen miles from Leeds. He could find his way all about this place. Walking along the middle of the road, when he heard any object approaching, he at once stopped, groped his way to the side of the road, and remained perfectly still until it had passed. Any one whom he knew, he was able to recognise by the sound of the voice, and by passing his hands over the face and body of the person. He could perceive the difference between a bright, sunny, and a dark, cloudy day, and could follow the motions of a candle without discerning what it was. He had been sent to school for some time, and by means of models and a raised alphabet, could by touch alone arrange the different letters into short words. I presented to him in succession a great number of different objects, each one of which he took into both hands, felt it most carefully over with both, then with equal minuteness with one, turning the object over and over again, in every direction; the tongue was next applied to it; and lastly, he applied it so near to the eye as to touch the eyelids, when he pronounced his opinion upon it, and generally with correctness, as to the nature and form of the object, when these were distinct. Thus he recognised books, stones, small boxes, pieces of wood and bone of different shapes, a broken piece of hard biscuit. A cube and a sphere he could readily recognise, saying the one was square, and the other round, and that both were made of wood; but a sphere which was made of perfectly smooth, hard wood, he was very confident was bone.

In an object where the angles were not very distinct, he made constant mistakes in the shape, first saying that it was square, then that it was round. Very bright light colours, when touching the eyelids, he could at once recognise, calling them all white; all dull and dark colours he said were black. Between a thin circle of wood and a sphere or a cube, he instantly decided by the hand alone. On putting half-a-crown piece into his hands, he immediately said it was money, but for long was undecided whether it was half-a-crown or a penny; however, after carefully turning it over for some time, so as frequently to bring every part into contact with the hand, then putting it to the tongue, and afterwards so close to the eye that it touched the eyeball itself, he said decidedly, "It is half-a-crown."

The lenses were very large, milky, with caseous particles, quite white and opaque; the capsules being clear and transparent. As is well known, in most cases, before this period of life, the lens itself has been absorbed, leaving only a leathery, opaque capsule, and, of course, not nearly so favourable for such observations as this one. After keeping him in a dark room for a few days, until the opaque particles of lenses were nearly absorbed, and the eyes clear, the same objects, which had been kept carefully from him, were again presented to his notice. He could at once perceive a difference in their shapes; though he could not in the least say which was the cube, and which the sphere, he saw they were not of the same figure. It was not until they had many times been placed in his hands, that he learnt to distinguish by the eye the one which he had just had in his hands, from the other placed beside it. He gradually became more correct in his perception, but it was only after several days that he could or would tell by the eyes alone, which was the sphere and which the cube; when asked, he always, before answering, wished to take both into his hands; even when this was allowed, when immediately afterwards the objects were placed before the eyes, he was not certain of the figure. Of distance he had not the least conception. He said everything touched his eyes, and walked most carefully about, with his hands held out before him, to prevent things hurting his eyes by touching them. Great care was requisite to prevent him falling over objects, or walking against them.

Improvement gradually went on, and his subsequent sight was, and now is, comparatively perfect.

This case, like those others referred to, when compared with what is observed during advancing infancy, will be found to be identical in its principal features, and exactly to correspond with the statements made as to the original powers of the eye. Thus rendering almost literally true the paradoxical definition of Swift, that vision is the art of seeing things that are invisible.

Colour, then, is the only idea for the conception of which we are absolutely dependent upon the eye; and since colour is the result of light, and cannot be perceived by any other sense than the eye, it would appear, that without this organ there could not have been any conception of colour. It may be difficult, and undoubtedly it is so, to separate our ideas of colour from those of extension and figure, yet it may be done, and there is no necessary connexion between them.

There are, however, not wanting writers who deny that light is even essential to colour. Amongst these is Müller, who maintains, that in a man blind from his birth, "it is evident that the sense might, nevertheless, have been no less perfect in him than in other men; for light and colours are an innate endowment of his nature, and require merely a stimulus to render them manifest." With submission to Professor Müller, I must venture to differ from him on this question, and to think that the man absolutely blind from birth, with the retina and optic ever so perfect, would not have had conception of colour any more than the absolutely deaf man would of sound. Even if we take Müller's own statement, it appears difficult to conceive how, if a stimulant be necessary, as he admits, to call forth the perception of colour, any other stimulus should give rise to the idea, unless this had been first obtained by the existence of light itself. It is undoubtedly true that light is not at all times necessary for the perception of colour, for whenever (as has also been shown at page 4) the retina is thrown into any motion or agitation, such as ordinarily is induced by light coming from external objects,—or even when a similar agitation is excited in the optic nerve or sensorium, the ideas of colour and tangible objects will be excited. Of this we have daily examples in *delirium tremens;* not only as regards the sense of sight, but with all the senses. Hence it is certain, that colours are sensations produced in our mind, and do not belong absolutely to either light, external objects, or even the retina, but are the modifications of the mind itself, which always stand connected with, and as resulting from, change in the organ of sight, and in the sensorium. But in order that an idea of colour be attached to these modifications, it is essential that colour should have been perceived from an external object. Words are only the arbitrary signs of ideas already perceived, in which there is no necessary connexion between the words and those ideas of the mind which they are employed to represent. Hence, if a blind man ask what is meant by a white, black, or red body, I can never inform him. It depends entirely upon the will of man to connect such words to such ideas. When I see a white body, I receive a certain idea to which I give any name I please. *A white body—corpus album—un corps blanc:* yet it is obvious there is no necessary connexion between the sound of these words and the coloured body of which they are the signs; any other might just as well have been fixed upon, and, indeed, in different countries, many others are so employed, and, therefore, a blind man, on hearing them, or any other words, can never receive the idea of a white body. These ideas are the modifications of the mind itself, and are only arbitrarily connected with certain changes excited in the optic nerve and sensorium, by the impulse received from the rays of light falling upon the retina. It is, therefore, in vain to seek to explain by words what colours are, since words are only the arbitrary signs of ideas already received; colours are not at all attached to words, or to changes excited in the auditory or olfactory nerves, but to those excited in the optic nerves alone; and, consequently, to know what colours are, we must first open our eyes, and receive those impressions upon our organs of sight, with which alone, when transmitted to the sensorium, those modifications of our mind, which we call colours, are connected.

CHAPTER III.

ON LIGHT, AND SUCH OF ITS LAWS AS ARE IMMEDIATELY APPLICABLE TO VISION.

I do not here propose to write a treatise on optics, but only to explain, in as simple a manner as I am able, something of the nature of light, and so much of its more elementary laws as is necessary to be known, in order to understand the principles of construction adopted in forming the eye of man, and other animals; to explain such of the phenomena observed during vision as are referable to optical laws; and briefly to illustrate the construction and action of the more common optical instruments now so commonly in use. Accordingly, no mathematical formula, nor any abstruse calculations, will be introduced. For those who wish to study optics as a science, books and treatises are easily to be obtained in abundance: therefore only the results of calculations and experiments directly applicable to vision will be given. Neither shall I enter at much length into the abstruse and difficult question which, for so long a time, has divided the opinions of philosophers, as to whether light is a positive entity—a substance, as was formerly almost universally believed, or it be merely the effect of a peculiar undulatory motion excited, by some bodies at all times, and by other bodies when in a certain condition, in a widely diffused etherial vapour, which now appears to be the more prevailing opinion, inasmuch as whichever of these opinions may ultimately be proved to be the more correct, it will in no wise effect the laws which light obeys in its passage through, or reflexion by, different substances.*

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* Nearly all modern philosophers adopt the undulatory theory of light; though some of the greatest authority very cautiously, and not as a fact, indisputably established, as quite as satisfactorily explaining all those phenomena of light with which the corpuscular theory deals, and also some most important

These laws must always remain the same. They are ascertained facts. Upon whatever gravitation may hereafter be found to depend, whether it be in itself an ultimate law, or only one phase of a still more general law, it obviously will in no way affect those glorious discoveries in astronomy of Newton and his successors. So with light, whether it be regarded as a material actually given off from a luminous body, an undulation in a subtile ether, or, as I am inclined to conceive, as one development or manifestation of a widely diffused inherent and beautiful general, if not universal, property of simple matter, of which heat, chemical action, galvanism, electricity, magnetism, and nervous action are also modifications, the laws which light itself obeys, and also the laws appertaining to these different phases, will remain the same.

It may, however, be advantageous, as leading to a more correct conception of some of the wonders of light, and the organisation of the eye, if we reflect a little upon a few of the astounding facts which are involved in the adoption of either the corpuscular or the undulatory theory; and yet one of these theories appears to offer the only explanation of the phenomena.

According to the corpuscular theory, light consists of molecules actually emanating from luminous bodies, which act by contact upon the retina, in the same manner as odoriferous particles act upon the olfactory nerve. According to the undulatory theory, the waves of light excite corresponding vibrations in the retina, in the same way as the sonorous vibrations of the atmosphere act upon the auditory nerve. How infinitesimal must the corpucles be! how inconceivably minute and rapid the luminous vibrations! They pass uninterruptedly through fluids and solids; they are separated, concentrated, reflected, and refracted, decomposed, and collected again, and leave no trace of their passage,

phenomena (as those of polarization), which the corpuscular does not. Yet formerly, at least in this country, the corpuscular theory, perhaps, in consequence of Newton having employed it, was all but universally received; and Dr. Porterfield, in his most learned "Treatise on the Eye, and the Manner and Phenomena of Vision," enters at length into the question, and maintains that the undulatory theory of different velocities in the waves producing different colours is altogether unsatisfactory, while that of different-sized particles is quite sufficient. However, in Dr. Porterfield's day, nothing was known of the extraordinary properties of polarized light, nor of the existence of the chemical rays, as distinct from those of light and heat.

or their presence; while the rapidity with which they strike all bodies would crumble the most solid substance into atoms, were the size of the particles, or extent of the waves, not less than anything we can conceive of. Through a minute hole, made by a small needle in a card, a man lying on his back may readily see all the objects in the celestial hemisphere. Yet the innumerable rays of light, whether they be corpuscles or undulations, which separately come from all these bodies, pass through this little hole without in any way interfering with or disturbing each other's motions. A common tallow candle, lighted, and placed upon the top of a high tower, may, on a dark night, be instantly seen all round for the distance of half-a-mile, so that in no space of a mile in diameter can the eye be placed in which some rays of light will not be received. Were all the particles, which now fill this large space, a moment before shut up in that little morsel of tallow, which as yet is not ponderably lessened? or can that little flickering flame possess power enough to instantly set in inconceivably rapid undulatory motion a substance which fills a sphere whose diameter is a mile across?

Whichever theory we adopt to explain the phenomena of light, we are led to conclusions that strike the mind with astonishment. According to the corpuscular theory, the molecules of light are supposed to be endowed with attractive and repulsive forces, to have poles to balance themselves about their centres of gravity, and to possess other physical properties which we can only ascribe to ponderable matter. In speaking of these properties, it is difficult to divest oneself of the idea of sensible magnitude, or by any strain of the imagination to conceive that particles to which they belong can be so amazingly small as those of light demonstrably are. If a molecule weighed a single grain, its momentum (by reason of the enormous velocity with which it moves) would be such, that its effect would be equal to that of a cannon-ball of one hundred and fifty pounds, projected with a velocity of one thousand feet per second. How inconceivably small must they therefore be, when millions of molecules, collected by lenses or mirrors, have never been found to produce the slightest effect on the most delicate apparatus contrived expressly for the purpose of rendering their materiality sensible!

If the corpuscular theory astonish us by the extreme minuteness and prodigious velocity of the luminous molecules, the numerical results deduced from the undulatory theory are not less overwhelming. The extreme smallness of the amplitude of the vibrations, and the almost inconceivable, but still measurable rapidity with which they succeed each other, were computed by Dr. Young, and are exhibited in the following account.*

As the altitude of sonorous waves determines the loudness of the sounds, so the altitude of luminous waves determines the intensity or brightness of the colour. As the perception of sound is produced by the tympanum of the ear vibrating in sympathetic accordance with the pulsations of the air produced by the sounding body, so the perception of light and colour is produced by similar pulsations of the membrane of the eye, vibrating in accordance with ethereal pulsations propagated from the visible object. As in the case of the ear, the rigour of scientific investigation requires us to estimate the rate of the pulsations of the tympanum corresponding to each particular note, so in the case of light are we required to count the vibrations of the retina corresponding to every tint and colour. It may well be asked, in some spirit of incredulity, how the solution of such a problem could be hoped for; yet, as we shall see, nothing can be more simple and obvious.

Let us suppose an object of any particular colour—a red star, for example—looked at from a distance. From the star to the eye proceeds a continuous line of waves; these waves enter the pupil, and impinge upon the retina; for each wave that thus strikes the retina, there will be a separate pulsation of that membrane. Its rate of pulsation, or the number of pulsations which it makes per second, will therefore be known, if we can ascertain how many luminous waves enter the eye per second.

It has been well ascertained that light moves at the rate of about 200,000 miles per second; it follows, therefore, that a length of ray amounting to 200,000 miles must enter the pupil each second; the number of times, therefore, per second which the retina will vibrate, will be the same as the number of the luminous waves contained in a ray 200,000 miles long.

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* See Lardner on Optics.

Let us take the case of red light. In 200,000 miles there are, in round numbers, 1,000,000000 feet, and therefore 12,000,000000 inches. In each of these 12,000,000000 inches there are 40,000 waves of red light. In the whole length of ray, therefore, there are 480,000000,000000 waves. Since this ray, however, enters the eye in one second, and the retina must pulsate once for each of these waves, we arrive at the astonishing conclusion, that when we behold a red object, the membrane of the eye trembles at the rate of 480,000000,000000 of times between every two ticks of a common clock!

In the same manner, the rate of pulsation of the retina, corresponding to other tints of colours, is determined; and it is found that when violet light is perceived, it trembles at the rate of 720,000000,000000 of times per second.

In the annexed table are given the magnitudes of the luminous waves of each colour, the number of them which measure an inch, and the number of undulations per second which strike the eye.

Colours.	Length of undulation in parts of an inch.	Number of undulations in an inch.	Number of undulations per second.
Extreme Red . .	0·0000266	37640	458,000000,000000
Red	0·0000256	39180	477,000000,000000
Orange	0·0000240	41610	506,000000,000000
Yellow	0·0000227	44000	535,000000,000000
Green	0·0000211	47460	577,000000,000000
Blue	0·0000196	51110	622,000000,000000
Indigo	0·0000185	54070	658,000000,000000
Violet	0·0000174	57490	699,000000,000000
Extreme Violet. .	0·0000167	59750	727,000000,000000

The preceding calculations are, as will be easily perceived, made only in round numbers, with a view of rendering the principles of the investigation intelligible. In the table, the exact results of the physical investigations which have been carried on, on this subject, are given.

For the purpose of explanation, light may be described to be an emanation proceeding from bodies, by which we are enabled to see them. All substances are divided into two classes; those from which the light originally proceeds—the self-luminous, and into those which merely reflect, or cast back the light which falls upon them from the self-luminous,—the non-luminous. In the first class, in which the light is original, we have the sun, the stars, lightning, electricity, the oxyhydrogen light, and, in fact, flame and highly ignited bodies of all kinds. In the second class are found, the moon, the planets, and their satellites, and almost every substance by which we are surrounded. When we enter a room in which there is only a single lamp, or a bright fire, we see the lamp or the fire by the light which proceeds directly from it, but everything else in the apartment is seen by the light which, in the first instance, is given off by the lamp or the fire, and falling upon the different articles, is by them reflected, and thus reaches our eyes.

Light moves in every direction in straight lines. This admits of easy proof. By boring a very small hole in a window-shutter, and admitting the light of the sun through it, a bright luminous spot will be found upon the wall, exactly opposite to the hole: the sun, the hole, and the spot will be in a straight line. Should there be dust, smoke, or fog in the apartment, the luminous line will be more distinctly visible from the hole to the spot. However small the hole may be, a portion of light will pass through it, and neither the direction nor progress of the light which passes through the hole will be in any way affected by its separation from the rest. The smallest portion which we can thus separate, even in imagination, is called a ray of light, and each ray is independent of all other rays. A collection of these rays is called a pencil of rays; and according as they are proceeding at equal distances from each other, separating from each other, or approaching to each other, they are denominated parallel, diverging, or converging rays, as shown in fig. 2, parallel rays,—3, diverging rays, in which R is the point from whence the rays radiate, — and 4, converging rays, in which F is the focus or point where all the rays are concentrated. These terms, however, the young student will not

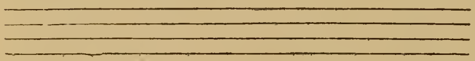

Fig. 2.

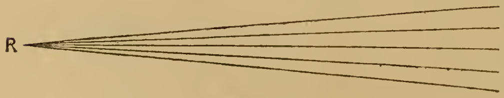

Fig. 3.

suppose to indicate actual rays and pencils of rays; they are merely terms of convenience, but are indispensable in describing optical phenomena.

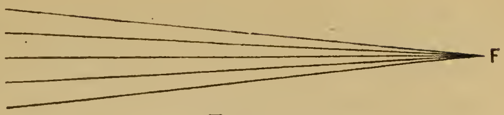

Fig. 4.

By observations made on the satellites of Jupiter when eclipsed, it has been determined that light travels at the rate of 198,000 miles in a second of time. In the statement made of the number of undulations of light, which is taken from Lardner's recent work on Optics, 200,000 miles is mentioned as the rate of motion per second. This is merely for the convenience of statement and calculation, round numbers being used.

The mean distance of the sun from the earth being ninety-five millions of miles, a ray of light arrives at the earth in eight minutes, thirteen seconds, after leaving the sun. These figures are easily spoken, but the naked statement is thereby hardly comprehended. They are so enormous, and the velocity so great, that the mind is, at first, quite incapable of recognising their immensity. Hence humble comparisons are necessary to assist our conception, and enable us to realize their vastness. In *one-eighth* of a second light moves through a space equal to the entire circumference of our earth. Now, supposing a bird of the swiftest wing were continually to fly, day and night, without any rest, it would occupy at least three weeks to pass over a like space: or taking an illustration with which everybody is familiar, were we disposed to accomplish the same distance by a fast train, and travelled forty miles an hour, without any stoppages, which is at least equal to any express train on the best-appointed railways, it would be a journey of 625 hours to pass over the same distance that light moves through in the one-eighth of a second of time.

A steamer, making 250 miles per day, would be occupied 1050 years in travelling from the earth to the sun. Huyghens computed a bullet-shot from a gun would be twenty-five years in passing from the earth to the sun, the relative velocity of light to the bullet being as 1,642,500 is to 1. Herschell says that it would be seventeen years before a cannon-ball reached the sun from the earth, supposing its velocity to continue uniform from the moment of its discharge; and so vast is the universe, that it is demonstrable that light cannot possibly arrive at our system from the nearest fixed star in less than five years, and telescopes disclose to us objects probably many thousand times more remote. The nearest fixed stars are 20,000000,000000, i.e. twenty billions of miles from the earth. If a ball travelled 500 miles an hour, it would not reach the nearest fixed star in 4,566,210 years. Had it begun its journey when Adam was created, it would be no further on its way than a coach which has to go from the Land's End to the North of Scotland, after it has proceeded about three-quarters of a mile.

Whenever light falls upon any substance, some portion of it is reflected or sent back again into space; and some part of the light enters the body, being either lost within it, or transmitted through it. When lost within it, the material is opake; but when the light passes through, it is transparent. All substances are transparent, translucent, or opake, according to the quantity of light which is transmitted through them, or absorbed or lost within them. This is in many cases merely a question of density and thickness in the material, for even metals, which are amongst the most opake of bodies, may be reduced to such a thin layer as to transmit light.

When light falls upon an opake, perfectly smooth, and well-polished substance, as a speculum or a well-polished steel plate, very little of the light enters the body; nearly the whole of it is reflected, and in all cases it is reflected according to particular laws, a consideration of which constitutes that division of optics called Catoptrics.

We have little to do in examining into the structure of the healthy eye with reflected light; but as recent improvements in the diagnosis of important diseases seated in the deeper structures of the eye have enabled us to avail ourselves of the assistance of light reflected into the eye by the opthalmoscope, by which the bottom of the organ is brightly illuminated, and also by what is called the catoptic test for cataract, in which variations and obliterations in the erect image of a candle held before the eye, formed by rays reflected from the anterior convex half of the crystalline capsule, and the inverted image of it formed by the posterior concave part of the capsule, are made important means of ascertaining changes in structure, it will be necessary to explain the action of reflecting surfaces. These will, however, be sufficiently illustrated by a few diagrams. Fig. 5 shows

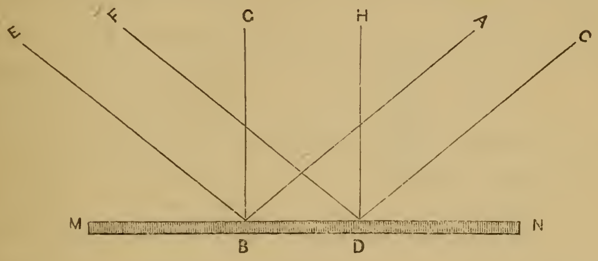

FIG. 5.

the manner in which parallel rays are reflected from a plane surface. Let M N be a plane speculum, upon which the parallel rays A B and C D fall in an oblique direction; for rays which fall perpendicular to the surface are reflected in a perpendicular direction; these rays will be reflected in the direction B E and D F. The rays A B and C D are called the incident rays, and B C and D F the reflected rays. If we now draw two lines, G and H, perpendicular to the surface of the speculum, touching it at the point where the rays A B and C D fall, we shall find that the reflected rays are precisely the same distance from the perpendicular lines as are the incident rays A B and C D; consequently A B G and E B G, C D H and F D H, are respectively the angles of incidence and reflection; and these angles being equal to each other, the rays, as they were parallel before reflection, will also be parallel afterwards, and consequently every part of the reflected image will bear the same relative position as it did in the incident image; but as the ray which before reflection was uppermost, after reflection is undermost, it of necessity follows that as the reflected beam of light is inverted, the image is also inverted. Whatever be the angle at which light falls upon a reflecting surface, and whatever be the form of this surface, whether plane, concave, or convex, the angle of reflection is in all cases, and under all circumstances, equal to the angle of incidence; this is, therefore, a general law.

Fig. 6 will illustrate the effect of concave mirrors. Let M D N be a concave mirror, whose centre of concavity is C, and A A A parallel rays of light falling upon its surface. All the rays of light will be reflected and conveyed into a focus at F; for as the ray A C D falls perpendicularly upon the surface of the speculum, it will be thrown back in the same direction, and by measuring the angles of incidence of each of the rays, and then making the angles of reflection equal to them, it will be found that they all meet in a point at F. Hence is easily understood how it is that this point should be so bright and hot, having all the rays of light and heat, which have fallen upon the entire surface of the speculum, here concentrated; as the law for the reflection of heat is the same as that for light.

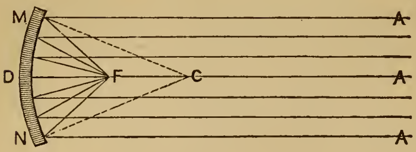

Fig. 6.

All images formed by concave mirrors are inverted, and generally positive, formed in front of the mirror, and smaller than the object when the image is nearer to the mirror than the object is, but larger when the object is nearer than the image is; the relative size of the image and the object being as the distance of the image from the mirror is to the distance of the object, as fig. 7 will show. Let A B be a concave mirror, from which rays of light fall from an object, M N. If we draw the reflected rays A *m* B *m* for the incident rays M A, M B, it will be found that they all meet in the point *m*, and there paint the extremity of the object M. In the same manner the cone of rays N A B passing from N, the other end of the object, will be reflected into a focus at *n*, and there paint that end of the object. If the object were placed at *m n*, then a magnified image of it would be formed at M N.

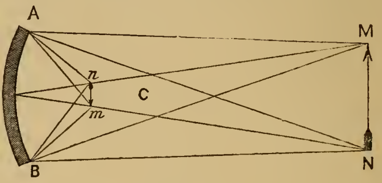

Fig. 7.

In convex mirrors the rays are rendered divergent, as fig. 8 will show, for parallel rays. Let M N, fig. 8, be a convex mirror, whose centre is C; and let A M, A D, A N, be parallel rays falling upon it. Draw two lines from the centre C, one through the point M to E, and the other through the point M to G; it will be found that these two lines are perpendicular to the surface of the mirror at the points M and N. The ray A M will be reflected in the direction M B, and the ray A N will be reflected in the direction N G, as the angle of reflection is equal to the angle of incidence, the angle E M B will be equal to the angle of incidence A M E, and E N G is equal to A N E. By continuing the lines M B G N backwards, they will meet at the point F, which is the virtual focus of the mirror, or the place from whence the rays after reflection appear to be proceeding. The place of the virtual focus approaching to or receding from the posterior surface of the mirror, as the incident rays are less or more diverging,—in other words, as the object is distant or near to its surface. Thus for parallel rays the virtual focus is at F, which is one-half of the radius of convexity C D, while in proportion as the object is brought near to the mirror, and the rays from it are more and more diverging, so does the virtual focus approach nearer to it, until both object and image touch the mirror.

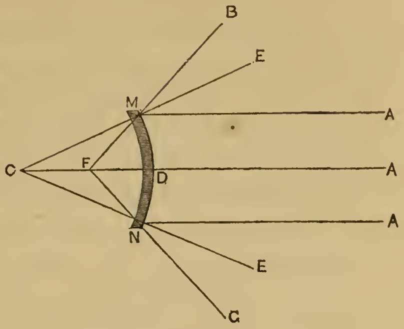

FIG. 8.

In *convex* mirrors the image is less than the object, and seen as though behind the mirror, the image being always a virtual one formed behind it. Let A B, fig. 9, be a convex mirror, whose centre is C; M N an object placed before it, and E the eye of an observer, also placed before the mirror, so that some of the rays reflected by the mirror from the object may enter it. As the angles of the reflected and incident rays are equal, we shall have the rays M D, M F, reflected in the direction D E, F E, and the rays N G, N H, reflected in the direction G E, H E, to the eye of the observer placed at E. If the lines D E, F E, are continued backwards, they will meet at *m*, and the lines G E, H E, will in like manner

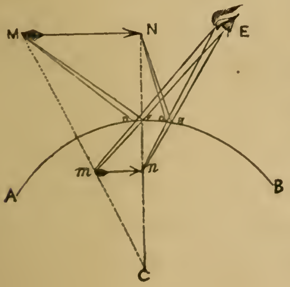

FIG. 9.

meet at n, from which points the rays will appear to come, as though the object were placed there; hence this is called the virtual image, because it is not formed by any rays there meeting, so as to be capable of being received upon any substance, as in the case of a positive image. The distance of the image will approach to the mirror, or recede from it, as the object approaches or recedes from it, until the object is so distant that the rays proceeding from it are parallel when they fall upon the mirror, when the image will be seen halfway between the centre C and the mirror. The size of the image is to the size of the object, as the distance of the image from the centre of the mirror is to the distance of the object from the centre; hence it follows that all objects seen in convex mirrors appear less than they actually are, in proportion to their distance from the mirror; the image and the object only being of equal size when the object actually touches the mirror.

When light falls upon a smooth transparent body, but little is reflected, though some always is, it being by that portion which is not transmitted we see the transparent body itself; for if no light were reflected, we should not see the substance, it is only by that light which reaches the eye from the body that it is visible. Thus, the more transparent the substance, the less are we aware of its presence, as less light is reflected. It is for this reason that the better the glass with which a window is glazed, the lighter is the room. Plate glass being more transparent than crown glass, it allows more light to pass through it, and reflects and absorbs less; so that the glass itself is less seen than is common glass, and hence the superiority of it. Not only does the nature of the substance affect the proportion of light which is transmitted and reflected, but also the direction of the incident rays, which, if very oblique, are more reflected; hence the dazzling effect of the rising and setting sun and moon upon masses of water and windows in the morning and the evening. In the middle of the day these are scarcely observable by the traveller; whereas when these luminaries are aslant, they become too bright to look at. In the former case more of the rays enter and pass onward, and those which are reflected are not in a direction to meet the eye so directly: in the latter a greater proportion of the rays are reflected, (as with the calorific rays,) and, reaching the observer's eye, produce the dazzling effect.

In all cases the light is transmitted through bodies in accordance with particular laws, a consideration of which constitutes the division of optical science called Dioptrics.

It is in strict accordance with these laws that an image of an object is formed upon the retina. The eye being to all intents and purposes a dioptrical instrument, it is necessary to ascertain the nature of the laws which regulate the transmission of light through transparent media, before we can understand in what manner a perfect representation of a tangible object is formed at the bottom of the eye, and the reason for the forms and densities of the different parts of the eye.

It has been stated that light moves in every direction in straight lines; this statement, however, is only true so long as the medium in which it moves is of uniform density; when this is so, there is not the smallest deviation to the right or the left; but the moment the density of the medium alters, so does the direction of the rays of light, provided the surfaces of the two media are not perpendicular to each other.

All rays of light which pass from a denser into a rarer medium, as, for instance, from glass into air, are turned from their original course in a direction away from the perpendicular; while every ray of light passing from a rarer into a denser medium, as from air into water or glass, is deflected towards the perpendicular; provided, as just mentioned, the rays of light strike the rarer or denser medium at an angle; for if the two surfaces are perpendicular to each other, the course of the ray is unchanged, however different their densities may be.

It is for this reason that a stick, which we know to be perfectly straight, when plunged into water, appears to be bent at the surface of the water; and also why things seen in the water are not seen in their exact position, this being always rather nearer to a line drawn perpendicular to the surface of the water than they appear to be in, from the rays of light which pass from them out of the water into the rarer medium, air, being deflected from the perpendicular.

From this property of light arise two most important laws, which are of so general application *(cæteris paribus)* as to constitute axioms. The first is, that in proportion to the density of the medium which the ray enters, as compared with that which it has just left, so will be the degree of its deflexion from its original course. Accordingly, we find that a ray of light in passing from air into glass is turned in a greater degree from its original course than it would be if it passed from air into water, in consequence of glass being denser than water. The second law is, that in proportion to the obliquity with which the ray strikes the new medium, so will be the extent of its refraction from its straight course. In other words, the ray entering into a denser medium from a rarer, and that leaving the denser, will always bear the same proportion to each other. The following three diagrams will sufficiently illustrate these premises.

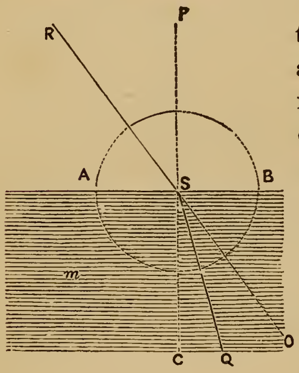

FIG. 10.

Fig. 10 shows what is meant by the incident and refracted ray, and also their relative positions. Let A B represent a circular board, or piece of card, along the surface of which a single ray of light is made to pass in an oblique direction, by holding a taper at the extremity of a small tube, R S. So long as the board is in air, the ray will continue to pursue a straight course from R to O; but if the board be plunged halfway into water, the ray will no longer be straight, but at the surface of the water, at S, will be turned towards its perpendicular line P C, and will then take the course of S Q; R S being the incident ray, and S Q the refracted ray. It will be seen that these rays are on the opposite side of the perpendicular line P C. This is always the case, and also that the angle of incidence in the rarer medium, P S R, is always larger than the angle of refraction in the denser medium, C S Q.

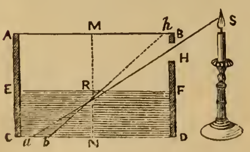

FIG. 11.

Fig. 11 shows a simple experiment by which any one may easily see how the ray of light is bent in passing into water. Let A B C D be an empty box, having a hole near to the top of one of its sides H; let a lighted candle S be placed at such a distance from the box as that a ray of light may pass through H, and form a round spot at *a*. Mark this spot, then pour water into the box, until it rises to E F; then it will be found that the spot of light has changed its situation from *a* to *b*, the ray S R *b* being bent at R: *a* R and R *b* are two straight lines which meet at an angle at the point R at the surface of the water. So that if a fish were lying at *b*, it would be seen by an eye at S, in the direction S *a*, and to shoot it with a ball, the gun must be directed to a point nearer to us than the point *a*.

Many a child and young person has been puzzled to understand an experiment with which it has often amused itself, as in fig. 12. Take a vessel of any kind,—a common basin will answer as well as any other. Place a sixpence upon the bottom of it, and then retire so far that the sixpence shall no longer be visible over the edge of the basin. Then without moving from the spot, direct some one to fill the basin with water, and immediately the sixpence will be brought into view. Let S A represent the ray of light reflected by the sixpence, and passing over the edge of the basin. So long as the basin is empty, this ray, according to the law just stated,—that, so long as the medium is uniform, light moves in a straight line,—will proceed to B, and consequently could not be seen by an eye at E; but so soon as the basin is filled with water, the ray S A, when it reaches the surface of the water, and passes into the rarer medium, air, is deflected from the perpendicular line *p*, into the direction A E, and consequently the sixpence becomes visible, and will be seen as though it lay at S′, although from the last experiment, as well as this, we know that its actual position is at S.

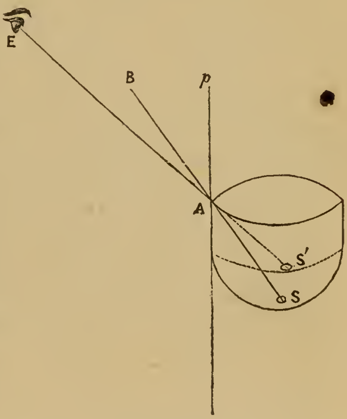

Fig. 12.

It has been stated, that in proportion to the density of the material, and the degree of obliquity of the incident ray, so will be the degree of deflection in the refracted ray. Formulæ are given in all works on optics for calculating and determining this latter from the former. It was formerly supposed that the angles of incidence and refraction always bear the same proportion to each other; this, however, is not the case, but it has been ascertained, that the sines of these angles always bear an exact proportion to each other, although the angles do not.

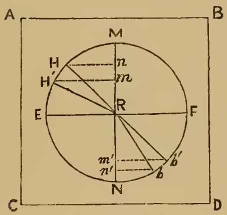

Fig. 13.

Let A B C D be a square piece of board upon which a circle has been described, as also the diameters E F and M N, perpendicular to each other; let a small tube H R be fixed to the board, so that it may be a moveable radius round the centre R. Let the board now be placed in a tub of water, so that the surface of the water may reach to E F, but without actually touching the end of the tube H R. When the tube is in the position M R, perpendicular to the surface of the water, admit a ray of light down the tube, and it will be seen to pass straight on to N, without any change in its direction, and if a sixpence be placed at N, it will be seen by looking through the tube M R; so that it is evident both that a ray of light falling perpendicularly upon a transparent denser substance, and also a ray of light leaving a dense substance to enter perpendicularly a rarer medium, undergo no change in direction. If the tube be now brought into the direction H R, and a ray of light be made to pass along it, the ray will be refracted at R in the direction R *b*. If we now draw a line from the point H, where the incident ray is intersected by the circumference of the circle, perpendicular to the line M R, we shall have the sine H *n* of the angle of incidence, and if in like manner we draw a line from the point *b*, where the refracted ray intersects the circle, perpendicular to the line R N, we shall have the sine *b n′* of the angle of refraction. On measuring these two lines, it will be found that the proportion which the sine of the angle of incidence bears to the sine of the angle of refraction is as 1·336 to 1. If the tube be now put into a more oblique position, as R H′, the incident ray will form a greater angle with the surface of the water, and accordingly it will suffer a greater degree of refraction, being bent as R *b′*. If the sine of the angles of incidence H′ *m*, and of refraction *m′ b′*, be measured, it will be found that they bear exactly the same proportion to each other as in the former case. As this appears constantly to occur, whatever be the obliquity of the rays, the number 1·336, which expresses this ratio for water, is called the index of refraction for water, or the refractive power of water.

Besides the density of the refractive medium, the chemical composition of it, or the manner in which its molecules are united together, also exercise considerable influence. These qualities, however, do not appear to possess the same unchangeable character as the density. It being of the utmost importance in the construction of optical instruments, to know exactly the refractive power of the medium employed, tables of the refractive effect of many different substances are given in almost every one of the more recent works on optics. It may be stated as one of the most general laws, that all combustible bodies possess a much higher refractive power than do incombustible bodies of the same density. It was a knowledge of this property that first led to the supposition of the true chemical composition of the diamond, from observing the much higher refractive power which it possesses than its density would account for. All hydro-carbons (as oils and resins), whether solid, liquid, or gaseous, are endowed, *cæteris paribus*, with very high refractive properties.

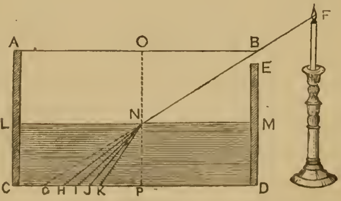

Fig. 14.

Fig. 14. Let A B C D be a square box, with a hole at the corner E, as in fig. 11, and let E be a candle so placed that a ray from it would fall into the box, through the aperture E. Supposing the box to be empty, then the ray will pass on in a straight line in the direction of the dotted line, and fall upon the bottom of the box at G. If water be now poured into the box, so as to reach up to the line L M, the ray will be turned in the direction N H; if, instead of pure water, a solution of salt in water be used, the course of the refracted ray will be N G; if oil of turpentine, the ray will be still more refracted into the direction N G; and if oil of aniseed be employed, the ray will be

brought still nearer to the perpendicular line O P, as at K: the refractive power of these different fluids being in this ratio.

It is obvious, then, that as all rays of light which fall upon a denser medium with an equal degree of obliquity are equally refracted, though all the rays will be turned from their original course, towards the perpendicular, yet every ray will preserve the same relative position with regard to all the other rays while within the denser medium, and after leaving it, as they did before entering it. Fig. 15 will illustrate this.

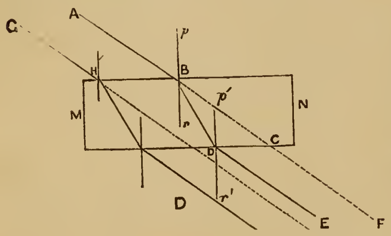

FIG. 15.

Let M N be a portion of glass, having two parallel sides, and A B a ray of light falling obliquely upon the glass after passing through air. It will be refracted in the direction B D, and drawn towards *p r*, which is a line perpendicular to the surface of the glass at the point of incidence; on reaching the opposite surface of the glass, at the moment the ray passes again into air, it will suffer a second refraction in the direction D E, but it will be observed by following the line *p′ r′*, which is perpendicular to the surface of the glass, that now the direction of the ray is turned in the opposite direction, being from the perpendicular. What is true of the ray A B is equally true of the second ray G H, and also of every other ray; consequently all the rays preserve the same position with regard to each other, after leaving the glass, as they did before entering it.

In order to obviate this parallelism, bodies have been constructed of different shapes, by passing through which the course of the rays of light may be variously altered, either being dispersed and widely separated from each other, or collected together into a focus. These bodies are of many shapes, as fig. 16 will show; yet they may, for all practical purposes, be arranged into two

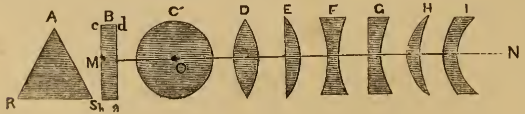

FIG. 16.

classes, according as they partake more of the form of the convex lens, or as they approach to the concave form.

A B C is an optical prism, formed of a solid transparent substance, having two plane sides A R and A S, which are its refractive surfaces, and a base, R S, which is equally inclined to the two surfaces.

B is a plane glass, in which the two surfaces are parallel to each other, as c b, d a.

C is a sphere having every point of its surface at an equal distance from its centre O.

D is a double convex lens. It is a solid having two convex surfaces which are opposed to each other. If the two surfaces are segments of a sphere of the same size, the lens is said to be an equally convex lens; but when the two surfaces do not correspond in convexity, the lens is an unequally convex lens.

E represents a lens having one of its sides plane, the other convex, being a plano-convex lens.

F is a double concave lens, in which both surfaces are concave, and like D it may have these surfaces equal or unequal, constituting an equal or unequal concave lens.

G shows a plano-concave lens, having one of its sides plane, the other concave.

H represents a lens, one of whose sides is concave, the other convex; but inasmuch as the two surfaces, if continued, meet, the convexity must be greater than the concavity, so that in action it resembles a convex lens: it is the meniscus.

I shows the form of a concavo-convex lens, where the two surfaces being continued, do not meet, in consequence of the concavity being greater than the convexity; hence its action is that of a concave lens.

A line M N is drawn through the centre of these lenses; it is called the axis of the lens. It will readily be perceived that these figures represent only sections of the lenses; they are seen in profile, but entire. The convex lens will resemble the outside of a watch glass, the concave lens the inside of it.

It is unnecessary to enter upon the rules for finding the precise degree of refraction which each of these forms of lens produces upon different rays of light. It may be stated generally, that the action of a concave lens is to disperse all rays of light which pass through it. Parallel rays are made diverging, diverging rays more diverging, and converging rays less converging. This effect will be in proportion to the greater or less part of a sphere which the lens forms; or, in other words, to the greater degree of slope, or hollowness, which its sides possess. Fig. 17 will show the effect of a double concave lens upon parallel rays; fig. 18, upon diverging rays; and fig. 19, upon converging rays.

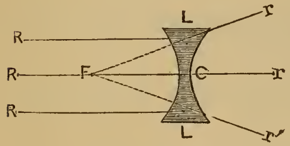

Fig. 17.

Let L L, fig. 17, be a double concave lens upon which fall the parallel rays R R R; R C, falling upon the centre, will pass through unchanged, while the two outer rays will be made to diverge in the directions L *r*, L *r*′, appearing as though the rays proceeded from a focus near to the lens at F.

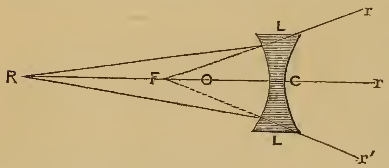

Fig. 18.

In fig. 18, diverging rays are seen proceeding from a focus R, to fall upon a double concave lens L L; as in fig. 17, the central ray R C falls upon the lens perpendicular to its surface, and therefore proceeds on unchanged in its direction; while the two outer rays, falling obliquely upon the surface of the lens, are thrown into the course L *r*, L *r*′, as though its rays proceeded from a focus F, much nearer to the lens than the actual focus R.

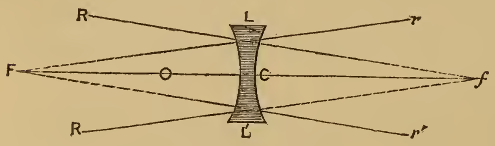

Fig. 19.

Fig. 19 shows the action of a double concave lens upon converging rays. Suppose R R are two rays proceeding with such a degree of convergence that they will meet in a focus at *f*: if a double concave lens be interposed, they will be separated from each other, and made to take the direction L *r* L *r*′, as though they proceeded from a focus F at some distance from the lens, thus becoming diverging rays.

Before proceeding to examine the effects of convex lenses upon rays of light, it will be proper to ascertain that of a body where the surfaces are parallel to each other, by which we shall at once perceive, that though the rays are somewhat concentrated, yet they never can be brought into a focus. This is a necessary consequence of what was illustrated in fig. 15, but which will be more evident by fig. 20. Let E F G H be a square portion of glass, having its anterior surface darkened, except the aperture C D, through which rays of light, proceeding from an object A B may be admitted. The ray A D will not proceed onward to I, but be refracted towards a line drawn perpendicular to the surface of the glass at D, and would fall at *i*; A C, instead of proceeding to L, will fall at *l*; B D at *m* instead of at M, and B C at *k* instead of at K, all being thrown nearer to the perpendicular lines at the surface of the glass. It will be evident, that as the rays of light are brought nearer to each other, any image formed by them will be smaller and lighter than if the rays had proceeded through air, the space between *i* and *k* being smaller than that between I and K; but a body with such a form is unable to collect the rays in a greater degree, and cannot concentrate them in a focus.

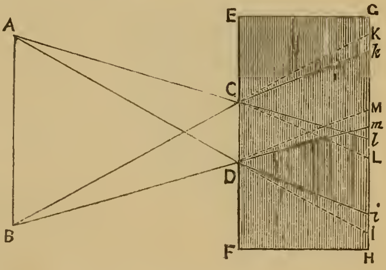

FIG. 20.

The action of convex lenses is altogether of an opposite character to that of concave. Fig. 21 will in some degree explain how rays of light are affected by a convex lens; but as it is of the utmost importance fully to understand their action, it must be examined at greater length than was necessary with that of concave lenses. L L, fig. 21, is a double convex lens, upon which parallel rays of light are falling. The ray R C, which strikes upon the axis of the lens, will pass through it unchanged; the rays R L, R L, will be refracted at the surfaces of the

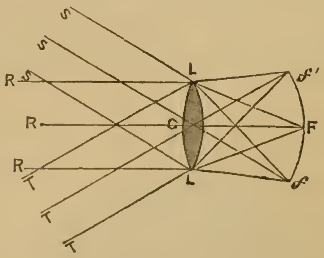

FIG. 21.

lens, and meet with the central ray in the axis at F. When the rays fall obliquely to the axis S L, S C, S L, and T L, T C, T L, the rays S C and T C, which pass through the centre of the lens, will suffer refraction at each surface of it; but as the two refractions are equal and in opposite directions, the finally refracted rays C *f* and C *f*′ will be parallel to S C and T C, while S L and S L, which fall near to the circumference of the lens, will be refracted in the direction of the central ray S, so that the three will meet in a focus at *f*. In the same manner T L, T L, will be refracted so as to meet T C in a focus at *f*′.

Bearing, then, in mind what has been already shown—that every ray of light passing from a rarer into a denser medium, which strikes upon it perpendicularly to the surface, passes on unchanged in its course, but that every ray which falls obliquely upon its surface is turned from its original course, and bent into a direction nearer to the perpendicular line, it will easily be understood that it will follow, by giving to any transparent body—a piece of glass, for instance—a sloping surface, that we may concentrate all the parallel rays of light which fall upon it into a focus at some point beyond it. That ray which falls upon the centre of the glass will proceed onwards in its course, while every ray which falls to the right hand of the centre will be refracted towards the left hand, and every ray which falls to the left of the centre towards the right hand. If, instead of passing from a rarer into a denser medium, the rays of light are proceeding from a dense into a rarer medium, we may also take advantage of the refraction which they then undergo, by giving to the posterior surface of the glass a sloping surface, and thus, as in the former case, collect all the rays into a point.

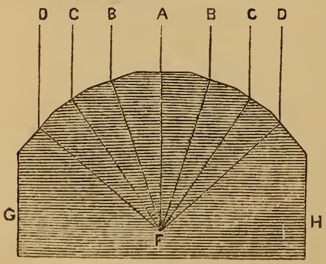

Fig. 22.

Fig. 22 will show the effect of a sloping surface upon parallel rays passing from air into glass. Let A B C D be rays of light, and G H a portion of glass cut into the form indicated; the ray A, falling perpendicularly, will not be changed in its direction; while B B fall upon the glass with some degree of obliquity, and are consequently turned from their parallel course; C C, meeting with a surface more oblique, are still more turned from their original direction; and D D, falling upon a still more oblique surface of the glass, are in a still greater degree deflected, and thus all the rays are made to meet at the point F.

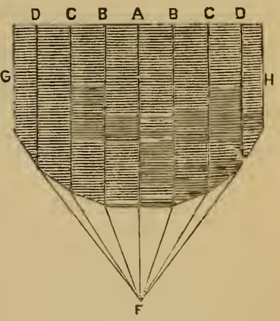

Fig. 23.

If the rays are passing from a dense into a rarer medium, as in fig. 23, we must in like manner give a greater degree of obliquity to the surface as we recede from the centre of the glass, and thus, as in the last figure, all the rays will be collected into a focus. The central ray, as before, in consequence of its perpendicularity, passes on unchanged. B, C, and D, being each brought in contact with the rarer medium successively, with a greater degree of obliquity, are proportionally more turned from the perpendicular line, and so brought into a focus.

The more sloping we make the surface of the lens, or in other words, the greater portion of a sphere it forms, the greater will be its power of refraction; and if both its surfaces are made convex, its power is increased in a corresponding degree, for then advantage is taken of the fact that the rays, in passing out of it into the air, undergo a second refraction in an opposite direction to that which they undergo on entering it; and as the direction of the two surfaces of the lens and the air are also opposite to each other, the direction of the rays will be in a continued curvilinear course, which they first receive on entering the lens.

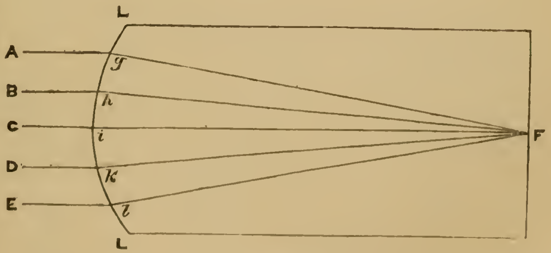

Fig. 24.

Let L L, fig. 24, represent the surface of a convex lens, and A B C D E, parallel rays of light falling upon it; as the central ray C falls perpendicularly, it passes on unchanged in the direction F; the rays B and D falling on each side of it with only a small amount of obliquity, will receive a certain degree of refraction at the points *h* and *k*, while the rays A and E, falling upon the lens near to its circumference, have a greater degree of obliquity, and thus receive a greater bending at the points *g* and *l*. If, however, we give to the posterior surface of the lens a slope, we produce a double convex lens, and the rays of light, in passing from it into air, suffer a second refraction, in the same course as was given to them by the first refraction, as explained by fig. 23, and also by fig. 25, where it is seen that the central ray passes both into and out of the lens in its original course, but that all the rays on either side of it, in addition to the deflection which they suffer at the anterior surface, *g h k l*, are made to undergo a second deflection at the posterior surface on emerging into air, at the points *m n p q*. Consequently, a lens having two convex surfaces is possessed of a much higher refractive power than a plano-convex lens, and collects the rays into a focus at a point nearer to it than one of the latter form.

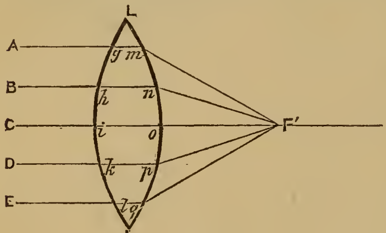

Fig. 25.

In consequence of this bending of the rays as they pass through a convex lens, it is an universal rule that an image so formed is in an inverted position relatively to the object; and the magnitude of the image is to that of the object as its distance from the lens is to the distance of the object from the lens.

If M N, fig. 26, is an object placed before a convex lens L L, every point of it will send forth rays in every direction. Those rays which fall upon the lens will be refracted to foci behind it. Since the focus, where any point of the object is represented in its image, is in the straight line drawn from that

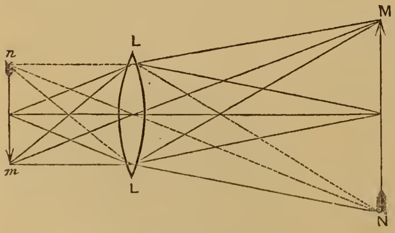

Fig. 26.

point of the object through the middle point C of the lens, the upper end M of the object will be represented somewhere in the line M C *m*, and the lower end N, somewhere in the line N C *n*, that is, at the points *m n*, where the rays L M, L N, L *n*, L *n*, cross the lines M *c m*, N *c n*. Hence *m* will represent the upper and *n* the lower end of the object M N. It is also evident, that in the two triangles M C N, *m* C *n*, *m n* the length of the image must be to M N the length of the object as C *m*, the distance of the image, is to C M, the distance of the object from the lens.

We are enabled, therefore, by a lens, to form an image of an object at any distance behind the lens we please, greater than its principal focus, and to make this image as large as we please, and in any proportion to the object. In order to have the image large, we must bring the object near the lens, and in order to have it small, we must remove the object from the lens; and these effects we can vary still further by using lenses of different focal lengths or distances.

When the lenses have the same focus, we may increase the brightness of the image by increasing the size of the lens, or the area of its surface. If a lens has an area of twelve square inches, it will obviously intercept twice as many rays proceeding from every point of the object, as if the area were only six square inches; so that, when it is out of our power to increase the brightness of the object by illuminating it, we may always increase the brightness of the image by using a larger lens.

Hitherto we have supposed the image *m n* to be received upon white paper or stucco, or some smooth and white surface, on which a picture of it is distinctly formed; but if we receive it upon ground glass or transparent paper, or upon a plate of glass, one of whose sides is covered with a dried film of skimmed milk, and if we place our eye six or eight inches or more behind this semi-transparent ground, interposed at *m n*, we shall see the inverted image *m n* as distinctly as before. If we keep the eye in this position, and remove the semi-transparent ground, we shall see an image in the air distinctly, and more bright than before. The cause of this will be readily understood, if we consider that all the rays which form by their convergence the points *m n* of the image *m n* cross one another at *m n*, and diverge from these points exactly in the same manner as they would do from a real object of the same size and brightness placed in *m n*. The image *m n*, therefore, of any object, may be regarded as a new object; and by placing another lens behind it, another image of the image *m n* would be formed, exactly of the same size, and in the same place as it would have been, had *m n* been a real object. But since the new image of *m n* must be inverted, this new image will be an exact image of M N, obtained by the aid of two lenses; so that by using one or more lenses, we can obtain direct or inverted images of any objects at pleasure. If the object M N is a moveable one, and within our reach, it is unnecessary to use two lenses to obtain an exact image of it; we have only to turn it upside down, and we shall obtain, by means of one lens, an image erect in reality, though still inverted in relation to the object.

In order to explain the power of lenses in magnifying objects and bringing them near us, or rather in giving magnified images of objects, and bringing the image near us, we must examine the different circumstances under which the same object appears when placed at different distances from the eye. If an eye placed at E looks at a man or boy, fig 27, placed at a considerable distance, his general outline only will be seen, and neither his age, nor his features, nor his dress will be recognised. When he is brought gradually nearer us, we discover the separate parts of his dress, till at the distance of a few feet we perceive his features; and when brought still nearer, we can count his very eyelashes, and observe the minutest lines upon his skin. At the distance E *b*, the man is seen under the angle *b* E *a*; and at the distance E B, he is seen under the greater angle B E A or *b* E A,′ and his *apparent* magnitudes *a b*, A′ *b*, are measured in these different positions by the angles *b* E *a*, B E A, or *b* E A.′ The apparent magnitude of the smallest object may therefore be

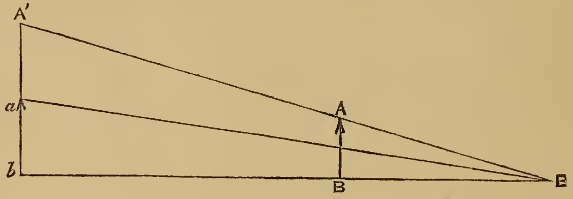

FIG. 27.

equal to the apparent magnitude of the largest. The head of a pin, for example, may be brought so near the eye that it may appear to cover a whole mountain, or even the whole visible surface of the earth ; and in this case the apparent magnitude of the pin's head is said to be equal to the apparent magnitude of the mountain, &c.

Let us now suppose the man, *a b*, to be placed at the distance of 100 feet from the eye at E, and that we place a convex lens of 25 feet focal distance, halfway between the object *a b* and the eye, that is, 50 feet from each,—then an inverted image of the man will be formed 50 feet behind the lens, and of the very same size as the object, that is, six feet high. If this object is looked at by the eye placed six or eight inches behind it, it will be seen exceedingly distinct, and nearly as well as if the man had been brought nearer, from the distance of 100 feet to the distance of six inches, at which we can examine minutely the details of his personal appearance. Now, in this case, the man, though not actually magnified, has been apparently magnified, because his apparent magnitude is greatly increased, in the proportion nearly of six inches to 100 feet, or of 200 to 1.

But if, instead of a lens of 25 feet focal length, we make use of a lens of shorter focus, and place it in such a position between the eye and the man, that its conjugate foci may be at the distance of 20 and 80 feet from the lens, that is, that the man is 20 feet before the lens, and the image 80 feet behind it, then the size of the image is *four* times that of the object, and the eye, placed six inches behind this magnified image, will see it with the greatest distinctness. Now in this case the image is magnified 4 times directly by the lens, and 200 times by being brought 200 times nearer the eye ; so that its apparent magnitude will be 800 times larger than before.

If, on the other hand, we use a lens of a still smaller focal length, and place it in such a position between the eye and the man that its conjugate foci may be at the distance of 75 and 25 feet from the lens, that is, that the man is 75 feet before the lens, and his image 25 feet behind it, then the size of the image will be only one-third the size of the object ; but though the image is thus *diminished three* times in size, yet its apparent magnitude is increased 200 times by being brought within six inches of the eye; so that it is still magnified, or its apparent magnitude is increased, $\frac{200}{3}$, or 67 times nearly.

At distances less than the preceding, when the focal length of the lens forms a considerable part of the whole distance, the rule for finding the magnifying power of a lens when the eye views the image which it forms at the distance of six inches, is as follows:—From the distance between the image and the object, in feet, subtract the focal distance of the lens, in feet, and divide the remainder by the same focal distance: by this quotient, divide twice the distance of the object, in feet, and the new quotient will be the magnifying power, or the number of times that the apparent magnitude of the object is increased.

When the focal length of the lens is quite inconsiderable compared with the distance of the object, as it is in most cases, the rule becomes this:—Divide the focal length of the lens by the distance at which the eye looks at the image, or as the eye will generally look at it, at the distance of six inches in order to see it most distinctly; divide the focal length by six inches, or, what is the same thing, double the focal length in feet, and the result will be the magnifying power of the lens.

Here, then, we have the principle of the simplest telescope, which consists of a lens whose focal length exceeds six inches, placed at one end of a tube, whose length must always be six inches greater than the focal length of the lens. When the eye is placed at the other end of the tube, it will see an inverted image of distant objects magnified in proportion to the focal length of the lens. If the lens has a focal length of ten or twelve feet, the magnifying power will be from twenty to twenty-four times, and the satellites of Jupiter will be distinctly seen through this single-lens telescope. To a very short-sighted person, who sees objects distinctly at a distance of three inches, the magnifying power would be from forty to forty-eight times.

In this account of the magnifying power of lenses, Sir D. Brewster estimates the distance of most distinct vision at six inches. This, for the majority of eyes, is, I think, too little; while that of ten inches, which is now commonly taken as the standard in calculating the magnifying power of microscopes and other optical instruments, is probably too great. For most eyes about seven or eight inches, so far as I can judge, appears to be about the ordinary distance of most distinct vision.

The effect of different length of sight will be easily understood by figs. 28, 29, and 30, in which, let E, fig. 28, represent an average-sighted eye; E′, fig. 29, a short-sighted eye; and E″, fig. 30, a long-sighted eye. Let the same small object, L M, be placed at the same distance from each eye; and let the distance of most distinct vision for E be E L, for E′, E′ L′, and for E″, E″ L″. Now, if by the interposition of a lens the object L M be made equally distinct to each of these three eyes, it will appear to the first at *l m*, to the second at *l′ m′*, and to the third at *l″ m″*. Its apparent magnitude to the three eyes will therefore be in the exact ratio of their respective distances of most distinct vision, and consequently the magnifying power of the lens to the short-sighted eye will be less than to the first, or the average-sighted eye, and to this less than to the last, or long-sighted eye. There is, however, as Dr. Lardner has justly pointed out, in the statement commonly made a most important consideration overlooked, and which, being of an opposite character, probably renders the magnifying power of the same lens for all eyes, whether short or long sighted, nearly the same. The size of the image is to the size of the object as the distance of the object is less or greater from the lens, and as the distance of the object from the lens must be less in the short-sighted person and greater in the long-sighted person than in the average-sighted, it follows that, practically, in the apparent size of the object there will be little difference, the different converging powers of the three eyes requiring these changes of distance in the position of the lens and the object.

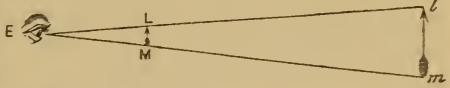

FIG. 28.

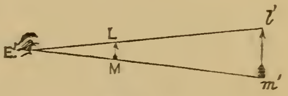

FIG. 29.

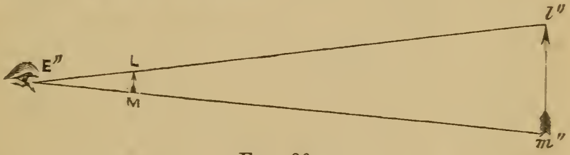

FIG. 30.

But as it is of the utmost importance in understanding the physiology of vision to have a clear comprehension of the precise mode in which convex lenses act in magnifying objects perceived through them, even at the risk of tediousness and repetition, it may be well to illustrate this by other diagrams, which will, it is hoped, render it quite clear. The construction of the eye in man and the higher animals is such that, in order for the crystalline lens to bring rays to a focus upon the retina, which is necessary for vision, it is requisite that these rays should enter the eye parallel, or only slightly divergent, or they will not form an image of the object upon the retina. As before said, the distance of distinct vision for small objects is not uniform, varying in different persons; and when the object is brought nearer to the eye than this limit, whatever it may be, the object becomes indistinct, though it may appear larger than when farther removed; the apparent size of the object being regulated by the angle which it subtends to the eye—that is, the angle which is contained between two lines drawn from the two extremes of the object to the centre of the eye, so that as the object recedes from the eyes, the angle becomes smaller and smaller, until almost inappreciable, unless the object be of immense size; and even then, as in the case of many fixed stars, the distance is so great as to render the angle so extremely small that the unaided eye cannot perceive it—the precise distance, however, varying, not only with the absolute size or visual angle of the object, but also with the degree of illumination and the colour of it.

In fig. 31 the lines drawn from the eye to A and R form an angle which is nearly twice as great as similar lines drawn to O and W, at double the distance; hence the first object will appear to the eye as nearly double the size of the second:—this constitutes the visual angle, or the angle of vision.

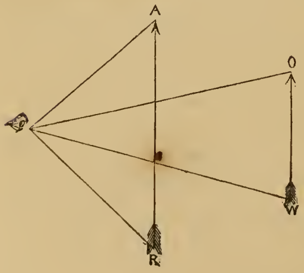

FIG. 31.

The use of a convex lens, when interposed between a near object and the eye, consists in its reducing the divergence of the rays issuing from it, so that they enter the eye with such a divergence as they would have had, had they proceeded from an object beyond the limit of nearest distinct vision, and thus there is formed upon the retina a distinct image. Let A B, fig. 32, represent a small object placed near to the eye, the rays from which are so diverging, that if they entered the eye they could not be brought into a focus upon the retina. But by interposing a double convex lens, and making the rays pass through it, they are rendered either parallel or so slightly divergent, that they are collected into a focus, and the eye sees them as though they had proceeded from a larger object placed at a much greater distance, as at C D. The difference between the actual size of the real object at A B, and the apparent size of the imaginary one at C D, constitutes the magnifying power of the lens. This power may be further illustrated by another diagram, fig. 33, in which the increase in the visual angle by a convex lens is also shown. Were no lens interposed, the arrow B′ C′ would be seen by the lines B C, proceeding from its extremities to the eye; but when more external lines are made to pass through a lens at F′ G′, they are bent in the direction F G, and therefore are seen as though proceeding from the points D E; and as the angle formed by the eye, and the lines F D G E, is more than double the size of the angle formed by the eye and B B′ C C′, the apparent size of the object will be proportionally increased.

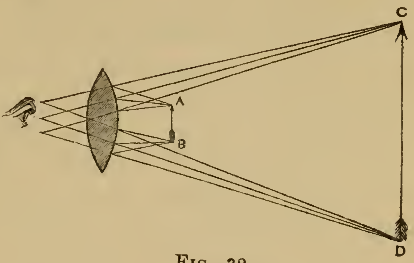

FIG. 32.

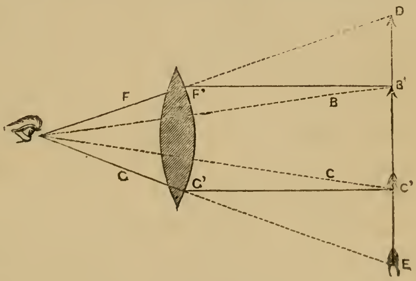

FIG. 33.

A lens thus used to look at or magnify any object is a *single microscope*, and when such lens is used to magnify the magnified image formed by another lens, the two lenses together constitute the *compound microscope*.

A single concave mirror is, upon the same principle, a *reflecting* *telescope*, for it is of no consequence whether the image of the object is formed by refraction or reflection. In this case, however, the image cannot be looked at without standing in the way of the object; but if the reflection is made a little obliquely, or if the mirror is sufficiently large so as not to intercept all the light from the object, it may be employed as a telescope. By using his great mirror, four feet in diameter and forty feet in focal length, in the way now mentioned, Dr. Herschel discovered one of the satellites of Saturn. When the image is received upon a small speculum, set obliquely, so as to throw it to an aperture in one side of the tube, in which is placed an eye-piece containing a convex lens, it constitutes the Newtonian telescope; or, if set opposite to the larger speculum, then the eye-piece is placed in an aperture in this. But these will be presently referred to. When such a convex lens is used to magnify an enlarged image, M N, fig. 7, produced from an object *m n*, placed before a concave mirror, the two constitute the reflecting microscope.

Bearing then in mind the two facts, that so long as light moves through a medium of uniform density, it proceeds in straight lines; and that when it enters a denser medium, obliquely to its surface, it is refracted; the direction and degree of its refraction being under our control, according to the shape given to the denser body; let us suppose ourselves called upon to construct an apparatus—say an eye, for instance—by which we can obtain an exact representation of an object, in which representation every part of the image shall have the same relative position to the others as they possess in the original object.

Two very different methods may be adopted. We may take advantage of radiation or of refraction, by either of which the image of an object may be obtained upon a proper recipient surface.

1st. *By radiation.* To obtain an image by the rays of light which radiate from an object, two kinds of apparatus may be employed. In the one, we must provide a series of very small tubes with darkened sides. These tubes must be so small as only to allow that ray of light which is exactly perpendicular to the tube to pass through it; the darkened sides absorbing or destroying every ray which may have entered the tube, but which has not fallen upon the orifice quite perpendicularly.

Now the most convenient and advantageous construction would be to make the recipient surface a convex sphere, or hemisphere, or some portion of a sphere, and to arrange the tubes as diverging radii from it. By this means an image would be formed upon the convex surface beneath the tubes, composed of each individual ray received from that point of the object which exactly corresponds to the direction of the tube which conveys it; and as every point of the image occupies exactly the same relative situation as those in the object itself do, a perfect representation of it would be formed in the erect position. But inasmuch as a very large portion of the light reflected from the object must necessarily be lost before reaching the recipient surface, and the quantity of light be very varying, according to the degree of divergence of the rays, being exceedingly small when near objects are regarded, it is obvious an image so formed would be very imperfect and indistinct. Such an apparatus, supposing the recipient surface to be sentient, might be proper enough to receive some impression from a distant object, and to command a large field of vision, but it would be extremely ill adapted for receiving images from, or giving rise to, correct and perfect impressions of near objects. It would possess no power of adjustment to the different distances of objects, and probably would not convey any notion of their different distances, all objects appearing to be equally near to the eye. It will, however, be seen, when examining the structure of the eyes of different creatures, that nature has in a most marvellous manner availed herself of this principle of light, and in many animals has constructed most complex eyes upon this plan; though, as if to show the correctness of the remark just made as to the imperfection of it, generally, if not universally, they are found in conjunction with eyes formed upon the principle of refraction. The more elevated and the greater the portion of a sphere such an apparatus forms, the larger will be the range from which it will receive rays of light.

Figs. 34 and 35 will illustrate an apparatus of the kind just spoken of. Let B B be a series of small tubes arranged as diverging radii perpendicular to the convex surface A. Supposing this to be the retina, an image will here be formed upon it, and conveyed by the optic nerve C to the brain, and they will also show

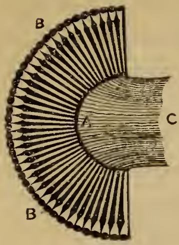

Fig. 34.

how necessarily faint must be the image formed, in consequence of the few rays of light which can be admitted by this method; for only those rays of light issuing from the points *f a b c d e* which have the exact direction of the radii of the convexity will be able to reach the bottom of the tubes. Thus though from all these points rays are radiating which fall upon the outer ends of all the tubes, only that ray which is exactly opposite to the tube will enter, as *a* to *a′*, *b* to *b′*; and so with the others; all the rest of the light will be excluded. The same figure will also show that in proportion as the apparatus forms a greater or less segment of a sphere, so will be the extent of the field which it will command. Thus if it be a hemisphere, it will receive rays from a corresponding extent of space; but if only such a segment as that the base would stretch from the lines *s s*, then the field would be so limited as only to command the space comprised between the lines R R.

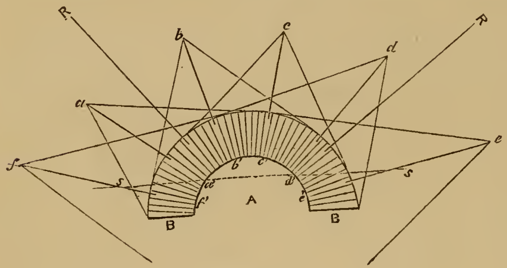

Fig. 35.

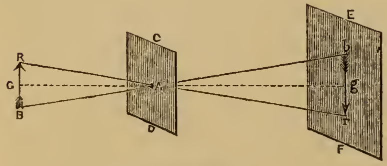

Fig. 36.

The second plan by which an image may be obtained by the radiation of light is by having an opaque septem, through which a small hole is made, interposed between an object and a recipient surface. This will be best explained by fig. 36. Let C D be a screen placed in a window; and having in it a small hole, A; E F will be a sheet of white paper placed in the darkened room. If an illuminated object R G B is placed on the outside of the screen, an inverted image of it will be observed thrown upon the paper *r g b*. In order to show this the better, Sir D.

Brewster recommends that the object should be of three colours; red at R, green at G, and blue at B. It will then be plain that the red light from R will pass in straight lines through the aperture A, and fall upon the paper at *r;* the green light from G will fall upon it at *g*, and the blue light from B will fall upon it at *b*, thus painting upon the paper an exact picture of the object. Or we may take a square box, into which no light is admitted except through a small circular hole in one side of it. If opposite to this opening an object intended to be represented be placed on the opposite side of the box, a faithful picture of the object will be observed in an inverted position, fig. 37. If the side of the box were made of ground glass, and only illuminated by the light entering the hole through which the rays forming the image passed, the inverted figure of it would be seen without trouble. Though the image thus formed is a faithful copy of the original, it is so faint as to be with some difficulty seen. This defect arises from the very small quantity of light which is admitted into the box (and also through the screen, fig. 36). For as every point of the object throws out rays, and only those which fall upon the small hole pass to form the image, this must necessarily be very faint, and useless for any optical purpose. If, with a view of obviating this faintness, the opening is enlarged, and more light let in, though certainly a brighter image is obtained, the outline becomes extremely indistinct and confused; and when the aperture is large, it is nearly or altogether obliterated. This arises from the enlarged aperture admitting rays from two adjacent points of the object to become mixed and throw their light upon the same point of the paper, and thus to create confusion.

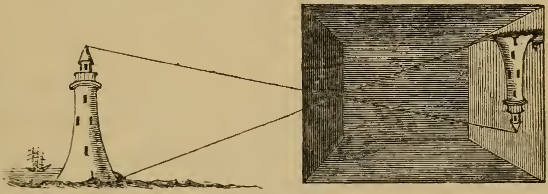

FIG. 37.

It appears, then, impossible by radiation to obtain an image which shall be distinct in the outline and at the same time bright in colour. The only mode by which this can be accomplished is to collect into a small space a great number of rays which proceed from corresponding points of the object. This brings us to the second method of obtaining an image:—by refraction, in which advantage is taken of the property of light to be turned towards a perpendicular line when falling obliquely upon a transparent surface. If, as in fig. 37, we make a large hole in the side of the box, and place within it a convex lens we shall be enabled to let pass all the rays which fall upon the opening, and to collect them into a small spot on the opposite side of the box, and thus by the great quantity of light obtain a bright and distinct representation of the object placed external to it. By so doing we have constructed a *camera obscura*, which is, as everybody knows, an apparatus formed of a dark chamber, having an aperture in one of its walls, where is fitted a convex lens; and within the chamber is a proper surface of plaster of paris, ground glass, semi-opaque paper, thin porcelain, or some similar material, upon which the rays of light that have passed through the lens in the aperture are received, and by which a correct representation, in an inverted position, of all objects within a certain range, dependent upon the size of the apparatus and the focal length of the lens, is painted.

Such is the precise construction of the eye itself, which is to all intents and purposes a camera obscura; the principle of formation and the mode of operation being in the two instruments identical; the difference being, that in the eye the surface upon which the image falls is fitted to excite the sensation of vision, while in the camera it is insensible; and also that as a mere optical apparatus the mechanism in the eye is infinitely more perfect than it is in the camera or in any other instrument which can be made by human ingenuity. For there are certain difficulties and imperfections in the construction of optical instruments, owing to the nature of light, the laws of its refraction, and the materials employed to produce this, which for long appeared to be of an insurmountable character, and have only been overcome to the extent they now have by an extraordinary amount of learning, labour, skill, expense, and the adoption of complicated contrivances; but which imperfections are not found to exist in the eye.

The difficulties which it is necessary to provide against are three.

1. The aberration of parallax, or distantial aberration.
2. The aberration of sphericity.
3. Aberration of colour, or chromatic aberration.

Aberration of parallax.—In order to understand this, it must be borne in mind that in proportion as an object is brought near to a convex lens, so does the image recede from it, as may readily be seen by holding a magnifying-glass between any object and a sheet of paper, when it is at once perceived that if it be wished to obtain a bright image, if the object be brought near to the glass, the sheet of paper must be carried further from it, and if the paper be brought near to it, then the object must be carried farther off. Now suppose, in any optical apparatus, there is a lens of such a form, that when the rays of light are proceeding from an object so distant as to be parallel, it will collect them into a focus at a certain distance behind it. It is obvious that if the object be so near to the lens that the rays are diverging when they reach it, they will not be collected into a focus at a point so near it; and this point will evidently recede from the lens, as the rays become more diverging from the nearer approach of the object. If then it be necessary, in order to produce any given effect, that the image of an object should be thrown upon a certain screen placed behind the lens, there must be some contrivance by which the distance between the screen and the lens may be regulated; otherwise no distinct image will be formed upon the screen, except the object is always placed at exactly the same distance before the lens. In some cases, where the object is distant, the rays would be collected into a focus before they reached the screen; in others, where the object is near, they would only be united at some distance behind it; in both the result would be a very confused and indistinct image.

In fig. 38, let C be a lens of such convexity that it will concentrate parallel rays into a focus at the distance of F behind it.

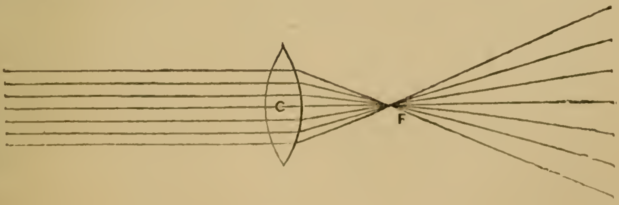

FIG. 38.

If the object approaches so near to the lens that the rays are diverging, as in fig. 39, then the focus will recede to the distance F; and if the object approaches still nearer, as in fig. 40, the focus will recede to a still greater distance, as at F.

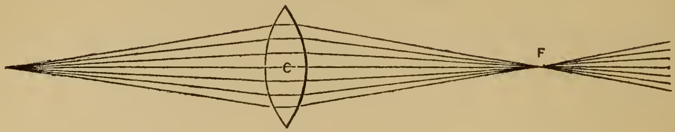

Fig. 39.

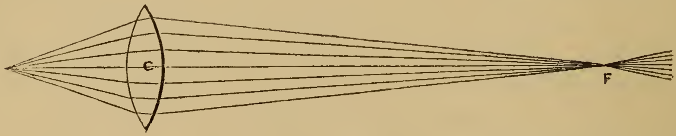

Fig. 40.

Fortunately for opticians, this defect is one that can be overcome without difficulty, and far more easily than either the aberration of colour or sphericity. All that is necessary is to have such a contrivance that the lens may be brought near to or removed from the part where the image is to fall. It is for this purpose that all microscopes and telescopes are provided with sliding tubes, or, where the power is high, with a rack-work and pinion, and with internal diaphragms or stops, by which, within certain limits, the extent of the field is enlarged, owing to the lenses being separated from or brought nearer to each other, the object, or the eye.

That the eye is admirably provided with means of exact adjustment to different distances is certain, inasmuch as it can receive correct images from objects so distant as that the rays of light from them are nearly, if not altogether, parallel; and also from objects placed so near to the eye, that the rays from them are very diverging, and thus the eye is enabled to range over a very extensive field of vision. The means, however, by which the adjustment is effected is not nearly so obvious. It is one of the most disputed problems connected with the physiology of vision; and has been made more so by the very exclusive notions which some very learned men have entertained upon the matter. To these attention will be directed in the chapter on the Physiology of Vision.

Fig. 41 will show the effect of this distantial aberration, did not the eye possess the power of correcting it. Let Q be an object at such a distance as that the refractive humours of the eye would collect the rays from it into a focus upon the retina at *q*. If an object were placed at S, the image would not be formed until the rays had passed beyond the retina, as at *s*. While, if the object were distant, as represented by the dotted lines R, the image would be formed by the rays meeting at *r* before they reached the retina.

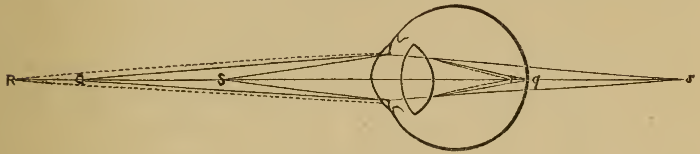

Fig. 41.

Aberration of Sphericity.—This is a defect of so important and difficult a character that for very long it defied the most learned and expert opticians to remove; and the extent to which it, as as well as the aberration of colour, have been overcome, are justly considered as amongst the greatest, if not the greatest, triumphs which learning and mechanical skill have been able by long and laborious perseverance to accomplish. In order to understand these difficulties, it is always necessary to recollect the two laws, which have been more than once mentioned, by which the degree of refraction light undergoes in its passage through transparent substances is regulated—the obliquity of the incident ray, and the density of the new medium.

In speaking of the refraction of light by a lens, it was said that the rays are collected into a focus; this, however, is not strictly correct, for in reality those rays which are nearest to the axis of the lens are made to unite in a point more distant from it than those rays which fall near to the edge of the lens. The reason of this difference is, that the degree of refraction, as has been just stated, always bears a direct proportion to the degree of obliquity with which the rays strike the denser medium; that is to say, the angle of refraction always is in fixed relation to the angle of incidence. It is therefore obvious, that as those rays which fall upon the edge of the lens strike its surface with a greater degree of obliquity than those which pass through near to its axis, they are consequently more refracted. This fig. 42 will render evident. Let L L be a double convex lens, upon which parallel rays of light are falling. A, being exactly in the axis of the lens, will pass onwards without deviation from its previous course. R″ L′, R″ L′, on each side of this, will undergo some degree of refraction, and meet with A in a focus at F. But R L, R L, which fall upon the edge of the lens, in consequence of the greater slope of the surface at this part, strike it with a greater degree of obliquity than R′ L′, R′ L′, and therefore will suffer a greater refraction, and will be made to unite nearer to the lens, than the other rays, as at *f*, from whence they will diverge, and continue into the plane G F H. If the image of an object be regarded in this plane, it will be observed to be bright in the centre, where the central rays are in focus, but at the edges there will be an indistinct fringe from the dispersion of the outer rays G *f* L, H *f* L; while if seen at *f*, or any intermediate point from *n* F, owing to the rays in the centre not having been brought into focus, it will also be indistinct. The distance from *f* to F is called the longitudinal spherical aberration, and from G to H the lateral spherical aberration.

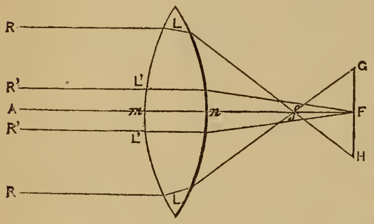

Fig. 42.

Philosophers have made most learned calculations, and opticians very elaborate experiments, in the hope of overcoming this great imperfection; and on its being shown by calculation that lenses which possess elliptical or hyperbolical surfaces would accurately concentrate all the rays of light into one focus, very laborious attempts were made to give these forms to lenses. The practical difficulties, however, of grinding a lens in any other form than the spherical are so great that the attempt has been abandoned, and only lenses of a spherical form are now used, it having been found impossible in a single lens altogether to obviate the defect; though by attending to the relative curves of its two surfaces a good deal may be accomplished towards diminishing this defect.

Substances having greater refractive power than glass were, it was at one time hoped, likely to prove efficient in avoiding this difficulty; as a less amount of curvature in their surfaces would of course produce an equal amount of refraction, as a greater curvature would in a less refractive material. It was therefore suggested by Sir D. Brewster that diamonds and other gems should be employed instead of glass in the formation of lenses, but after many experiments the attempt has been abandoned; for beside the cost, it is found that their substance is not equally refractive throughout, in consequence of their structure not being perfectly homogeneous. Moreover, their transparency is not equal; often they are coloured; and they possess a double refractive property.

Happily, in recent times opticians have been enabled, by combining two or more lenses of different forms, to make the varied forms or positions of these glasses so opposed to each other that the aberration produced by one glass is in the contrary direction of that caused by the other; and something after the fashion of two negatives destroying each other, these two aberrations ingeniously are made to correct each other, and in a very great degree, though perhaps not absolutely, to overcome what formerly was thought to be altogether insurmountable. Fig. 43 will show the action of the doublet, as it is called, and to which we shall presently have again to refer, on account of its influence in correcting aberration of colour; but at present, to render the matter more simple, its relation to aberration of sphericity will only be illustrated. By this it will be perceived that the ray of light which passes through nearest to the edge of the first lens, and consequently undergoes the greatest amount of refraction, is made to pass nearest to the axis

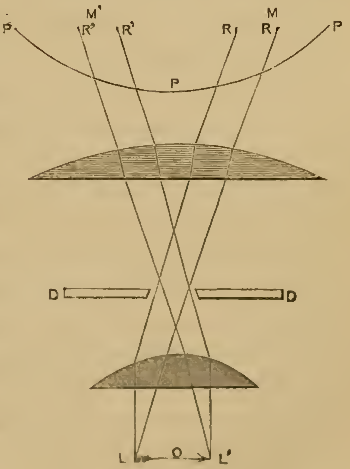

Fig. 43.

of the second lens, where it is necessarily less refracted than the ray which, having passed through the first lens near to its axis, is now made to pass nearest to the edge of this second lens. By calculation and experiments, and by the interposition of a diaphragm, or stop between the two lenses, to cut off those rays which pass too obliquely to be corrected, such a form may be given to the two lenses as that the result of the two aberrations shall be, unless a very high power is employed, practically to destroy each other. But, however carefully a doublet of this form may be constructed, there must necessarily be some amount of error, as the central pencil will occupy the same relative position in both lenses, the correction of this consequently will be imperfect, and all those rays intermediate between the centre and the margin will vary according to their distance from one or the other. This imperfection has led to the construction of the triplet, in which, instead of two lenses, three lenses elaborately formed of different kinds of glass, having different densities, are employed; though as this rather belongs to the next error, at present it will be sufficient to point to the diagram fig. 44, as showing the position of these glasses to each other.

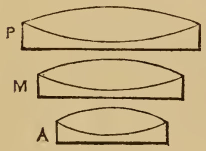

FIG. 44.

Fig. 43 well illustrates the action of the doublet, where P P P represents a portion of the eye, into which the rays of light are passing; D D the diaphragm between the two lenses, which will prevent those rays which have passed through the first glass too obliquely to be corrected by the second, from passing on to it; L L′ represents the object. Each of the pencils of light, from the extremities of the object L L′, is rendered eccentric by the stop; and the ray that passed through the first lens near to its centre is made to pass near the margin of the second lens, and also on the opposite side of the common axis O P, as will be seen by following the lines L′ R′ and L R, which pass through the first lens near to its margin, and L′ M′, L M, near to the axis; on the contrary, the rays in the second lens, L′ R, L R, pass near the centre, and L′ M′ L M near to the edge.

In the eye of man and animals a perfect example has been set of how a single lens may be constructed so as to be perfectly free from spherical aberration. For though a single convex lens is employed, it is made unequally convex on its two sides, which, as we have already mentioned, materially tends to correct spherical aberration; and, most beautifully, advantage is taken of that law of light, that in proportion to the density of the medium, so is the degree of refraction. The crystalline lens is more solid and dense at its axis than at its circumference, the increasing density, from the edge to the centre, being so graduated and progressive as exactly to counterbalance the decreasing obliquity of its surfaces, while the transparency of it is uniform. Thus, the greater density of the middle parts refract precisely as much as the greater obliquity of the edges.

Chromatic Aberration.—Light has hitherto been spoken of as a simple body, but this is not correct, or chromatic aberration would not occur; this results from white light not consisting of homogeneous rays, but being composed of variously coloured rays, in such proportions that, when undisturbed, white light is the result of the admixture. When, however, white light is refracted, it is decomposed, and the different rays are separated from each other. This quality of light has, in the construction of optical instruments, proved a difficulty of even a more formidable character than spherical aberration. Indeed, so great and perplexing has it been, that Newton believed it never could be overcome.

When a screen, having only a very small hole in it, is placed in a window, and the room is thus made dark, a luminous white spot is seen upon the wall opposite: if, now, a prism (A, fig. 16) be interposed, the white spot will disappear, and instead of it, an elongated variously coloured image will be perceived upon the wall, somewhat above the place of the white spot. In this image seven distinct colours may be traced—red, orange, yellow, green, blue, indigo, and violet. The red colour is the lowest, and the violet the highest in the image, showing that the different coloured rays are possessed of different degrees of refrangibility, and also that as the violet is turned in the greatest degree from its original course, it is the most refrangible, and, in like manner, the red the least so of all the rays. This coloured image constitutes the solar spectrum, and may be observed on a grand scale in the rainbow, where the falling drops of rain act as prisms; and is constantly seen in rooms where there are cut glass pendants, so commonly used as ornamental articles, when the sun shines. It is illustrated by fig. 45, where S L is a beam

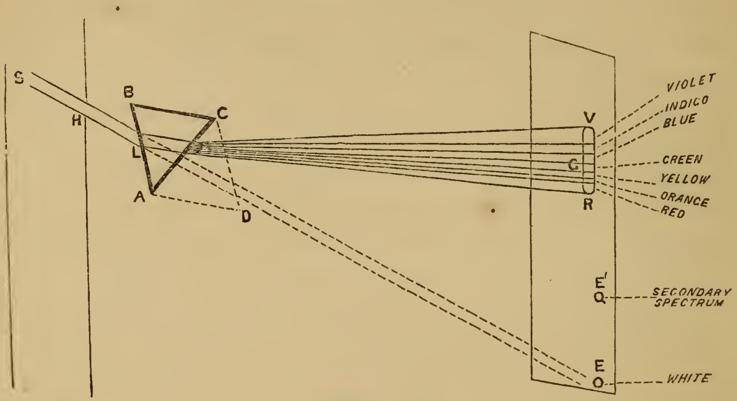

FIG. 45.

of white light, admitted into the room through the small hole H in the window-shutter, and which, when not interrupted, falls upon the screen as a white round spot at E. On the prism A B C being interposed, the spot disappears, and the elongated mark V R is seen, in which, in the order marked, the seven different colours appear.

As solar light is resolved by the prism into the various coloured lights seen in the spectrum, it should follow, that if these coloured rays can be again collected into a single spot, white light should be reproduced. This is found to be the case. White light may be decomposed into its constituent coloured rays, these may be again collected together, forming white light, and again be dispersed into coloured rays. Fig. 46 will show this. Let a ray of light, after

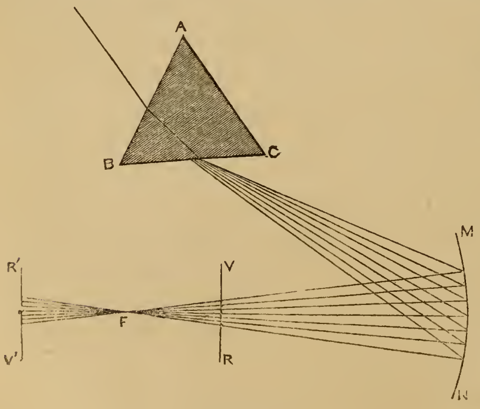

FIG. 46.

passing through the prism A B C, be received upon a concave speculum M N, where the spectrum will be formed, and from thence reflected to the focus F, where the different coloured rays will form white light, and again diverge, the ray R F passing in the direction F R′, and V F in the direction F V′.

If now a screen be interposed between F and the reflector M N, the spectrum will be seen upon it, as at V R; and as the screen is moved towards F, the spectrum will gradually diminish in size, the extreme rays approaching each other until F is reached, when the colour of the different rays disappears, and a colourless white spot is formed.

Just before the screen reaches F, the white spot will be seen fringed at the top with the colours forming the upper end of the reflected spectrum—violet, blue, and green, and at the bottom with those forming the lower end—yellow, orange, and red, as these rays have not yet completely combined into a focus; while, if the screen be moved to a similar distance beyond F, there will also be a coloured fringe surrounding the white spot, but the position of the colours will be reversed, red, orange, and yellow forming the upper, and green, blue, and violet the lower; and if the screen be removed still further beyond the point where a white spot is formed, the separate colours of the spectrum will be exhibited, but in a reverse position to that upon the speculum, the red being uppermost, and violet the undermost, which change is at once seen to arise from the rays intersecting each other at the focus F.

The same fact of white light resulting from a combination of coloured rays may be also verified by a simple experiment, which is easily made. Take a piece of cardboard blackened, with an aperture cut in it, as at fig. 47, and also another piece of cardboard, with a ring of the same breadth as the hole in the first piece, and let there be painted upon this ring, in the same relative positions and proportions as they occupy in the spectrum, the seven colours, as indicated by R O Y G B I V; then attach these two pieces of cardboard, the latter behind the first, by means of a spindle run through their centres, and so that the first is stationary, while the coloured ring moves with the spindle; and to this communicate a very rapid rotatory motion by means of multiplying-wheels; when, instead of the seven distinct colours being seen through the aperture, a grey

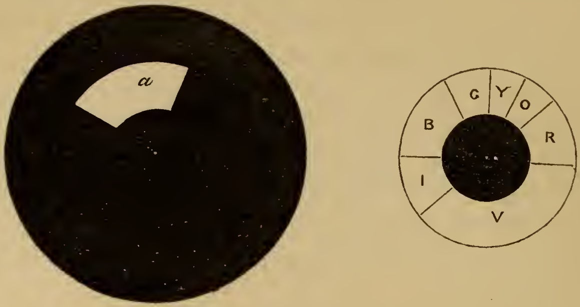

Fig. 47.

white will appear: the brighter are the colours used in painting the ring, the purer will be the white caused by the revolution of the card; and could we make the artificial colours as brilliant and intense as those of the spectrum, the white would be as clear and bright as that of nature. By omitting some of the colours, then the colour produced will be that caused by a mixture of those which are used; provided only the card be revolved with sufficient rapidity to mingle them: thus, if only red and yellow be used, orange will be seen; if blue and yellow, green; and if blue and red, then indigo or violet, according to the proportions of red and blue used.

The experiments of Sir D. Brewster have been of the most laborious and ingenious character, and have led him to adopt a different theory of the nature and composition of the solar spectrum from that of Newton, and which has received the sanction of many authorities at the present day.

Brewster supposes, that instead of seven, there are only three primary colours; the white light of the sun being composed of red, yellow, and blue rays. He infers that at each point of the spectrum these three colours are all present, combined in various proportions, the colour of each part being determined by the proportion of these three colours in it. In the red space, the proportions of yellow and blue are those exactly necessary to produce white light, but that the red is in excess; that portion beyond what is necessary, in combination with yellow and blue, to produce white light is in excess, and reddens the part. So in the same manner, in the yellow space, blue and red are in due proportions to form white light, but that yellow is in excess, and hence the yellow appearance; and in the blue, the yellow and red are in just quantities, but the blue is in this part in excess, and causes the blue space.

According to this theory, the orange, green, indigo, and violet are secondary colours, resulting from combination of red, yellow, and blue, which are thence called primary. Fig. 48 will more clearly explain how these three primary colours may be supposed to produce the tints of the spectrum. Let M N represent the prismatic spectrum, with its usual tints. The curve M R N represents the varying intensity of the red spectrum, M Y N that of the yellow, and M B N that of the blue spectrum. The distance of each part of these curves respectively from M N is understood to be proportional to the intensity of the colour of that part, and the relative length of the perpendicular included within each curve represents the proportion of the intensities of the combined colours. Thus at the point *p*, the three colours are mixed in the proportions of the lengths of the perpendiculars *p n*, *p' n*, *p'' n*, the first representing the proportion of yellow, the second red, and the third blue; the yellow and red predominating, the colour at this point will be orange.

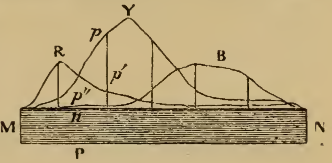

Fig. 48.

As this property of being decomposed, when refracted by passing through a medium of different density, is common to all white light, whether proceeding direct from luminous bodies or reflected from non-luminous, it greatly affects the formation of images by all kinds of lenses, and under all circumstances. If the image be seen in one place, it is coloured violet, in another red, and if in a place intermediate between these two points, instead of presenting the distinctness which, if formed of only one kind of rays, it would do, it is confused and indistinct, from the fringes of various-coloured rays not meeting in one focus. Let C, fig. 49, be a double convex lens, upon which rays of light are falling; the central ray A will pass on through the axis C of the lens, but the lateral rays S S' will be considerably refracted, and in so being, will be decomposed; the lines L L' *r* representing the violet rays, which suffers the greatest degree of refraction, and L′ L *r* the red, which, not being so refrangible, pass farther from the lens before being collected into a focus; the consequence of this is (as in fig. 46), that if a screen were placed at *v*, the image would be seen of a violet colour, only violet rays forming it; if placed at *r*, it would appear red; and if at *b*, variously coloured and indistinct; because hardly any of the rays would be in focus, the most refrangible having met, and being again divergent, the least refrangible not having met.

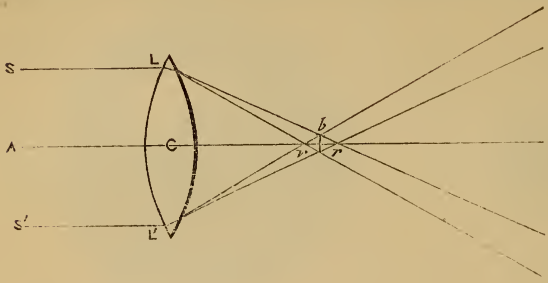

Fig. 49.

Newton's opinion as to the impossibility of overcoming the aberration of colour, was founded upon the assumption, that the degree in which the various rays are refracted by different bodies is in all cases uniform; but shortly after his time, it was discovered that substances vary in this respect, affecting the rays differently, some substances refracting one kind of rays more that others. Dolland, taking advantage of this circumstance, made lenses of two portions of different glass, one portion being crown glass, the other flint, by which the chromatic aberration was considerably diminished. Dr. Blair made the compound lens still more perfect, by enclosing muriate of antimony between two convex lenses of crown glass. Since his time, successive philosophers have calculated formulæ, and ingenious opticians have worked them out, with such skill, that by using the improved doublet of Wollaston, and the triplet of Holland, in which each lens is composed of a plano-concave lens of flint glass, and a double convex lens of crown, the two being accurately ground to each other, and cemented together by a highly refractive cement,—a hydro-carbon,—as one of the essential oils, Canada or copaiba balsam, &c.; the defect, for a simple instrument, has been removed; and, as with spherical aberration, by making two errors correct each other. When a compound instrument is used, by making the error of the eye-glass correct that of the object-glass, a freedom from chromatic aberration is obtained, which is justly regarded as the crowning glory in the construction of optical instruments. A section of a triplet lens is given at fig. 44, in which are seen the three lenses, each being composed of a plano-convex lens of flint-glass, and a double convex one of crown glass, so that, in reality, each lens consists of six lenses. Fig. 50 shows the action of the doublet in correcting the aberration of colour. By referring to fig. 43, it will be seen that this figure is a very similar one to that; having, however, in addition, the dotted lines. In fig. 50, the continuous lines L R R and L′ R′ R′ represent the red rays, and the dotted lines L B B and L′ B′ B′, the blue rays; by following these lines, it will be evident that as the blue rays are most refracted by the first lens, by crossing each other at the diaphragm, as they proceed to the second glass, they are carried to the outer side of the red rays, falling nearer to the margin of the lens, and thus, by undergoing a greater degree of refraction than the red, they emerge nearly parallel with them, and, consequently, all the rays are almost colourless to the eye, inasmuch as white light results from the combination of all the coloured rays.

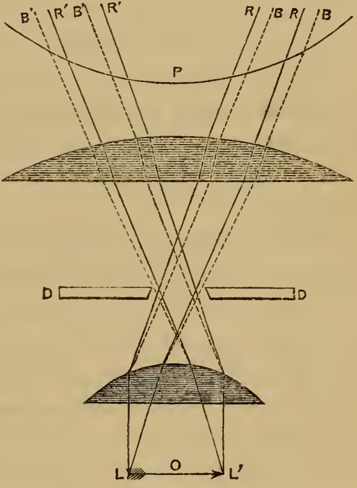

FIG. 50.

Yet the eye is an achromatic instrument, from which a lesson might have been most advantageously taken in the construction of artificial instruments. I am aware that more than one celebrated mathematician and optician does not regard the eye as an achromatic apparatus, and that Sir D. Brewster states that "no provision is made in the human eye for the correction of colour, because the deviation of the differently coloured rays is too small to produce indistinctness of vision." In this opinion, I submit, Brewster is wrong. The action of the eye is perfect, and I would ask the optician to produce a more beautiful specimen of a triplet lens, composed of structures of different densities, than can be seen in the eyes of man and animals. If the elaborate object and eye-glasses of optical instruments, which have occupied so much time in perfecting, are rendered achromatic by such combinations, why should not the same effects ensue from similar, and certainly *at the least* as perfect, combinations in the eye? Where will a more beautiful triplet, with its interposed diaphragm, be found than is to be seen in the cornea, aqueous and vitreous humours, with the double convex crystalline lens, with its unequal surfaces, and the floating diaphragm or iris, which we shall see is placed precisely where it ought to be? But this, and other matters belonging to the physiology of vision, must again be referred to after the structures have been examined.

Before leaving this division of the subject, it is proper to notice as briefly as possible the construction of the compound microscope and the telescope, as it will not only materially illustrate the subject of vision, but will also serve to show what labour and ingenuity have been required to overcome those difficulties arising from the nature of light, of which we have been speaking, and which, as I have said, I believe, in the structure of the eye, has been completely provided for.

On the Microscope.—In order to understand the different parts entering into the composition of a perfect object-glass for the compound microscope, it must be shown, first, how the rays of light comport themselves in their passage through a compound microscope—one of the ordinary kind, that is not achromatic. Fig. 51 represents a compound microscope of two lenses, A B being an object, C D the object-glass, and L M the eye-glass. The rays proceeding from the object A B are acted on by the lens C D, and are brought to a focus at B′ A′; but not being intercepted, there they cross and pass on till they reach the eye-glass L M, by which they are rendered nearly parallel; and as each reaches the eye at E, the image B′ A′ answering as an object to the single lens L M. The magnifying power of the compound microscope depends on two circumstances; first, the focus of the lens, that is, the distance of C A or D B;

and, secondly, the posterior focus C B′ or D A′; the power may be increased by substituting a lens of shorter focal length than C D, or by making the distance between C D and L M greater, and by the addition of a second lens at the eye end; the field of view is by this much increased, and we have formed what is termed an eye-piece; but by this arrangement, nothing has been done to diminish either the spherical or the chromatic aberration. One very great advantage which the compound has over the simple microscope, besides the great magnifying power, is that the field of view is large and equally good in all directions, whereas, in the simple, the field is small and only good in the centre. However well an instrument of this kind be constructed, it will fail to exhibit even many of the ordinary test-objects; it is, therefore, unfit for the purposes of scientific investigation, for in the diagram given at fig. 51, it must not be supposed that the image of the object formed by B′ A′ is a correct one; on the contrary, all the space between that arrow and the one drawn immediately above it, is occupied by an infinite number of variously coloured images of different sizes, those nearest C D being blue, and those most distant red; the effect of which is to destroy definition, and to render the image obscure. To overcome all these difficulties has been a labour of years.

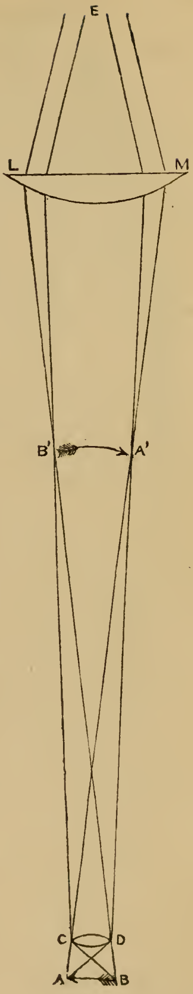

FIG. 51.

A section of a modern compound achromatic microscope, as manufactured by our best makers, is represented by fig. 52, where O is an object, and above it is seen the triple achromatic object-glass, in connexion with the eye-piece E E, F F; the plano-convex lens E E being the eye-glass, and F F the field-glass, and between them at B B a dark stop or diaphragm. The course of the light is shown by three rays drawn from the centre, and three from

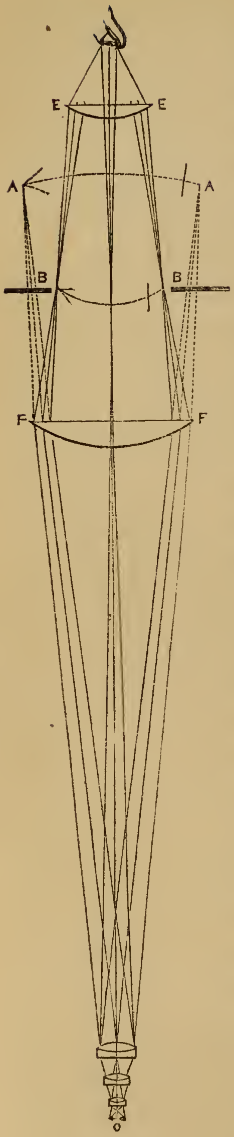

Fig. 52.

each end of the object O; these rays, if not prevented by the lens F F, or the diaphragm at B B, would form an image at A A; but as they meet with the lens F F in their passage, they are converged by it and meet at B B, where the diaphragm is placed to intercept all the light except that required for the formation of a perfect image, the image at B B is further magnified by the lens E E as if it were an original object.

"If we stopped here," says Mr. Ross, "we should convey a very imperfect idea of the beautiful series of corrections effected by the eye-piece, and which were first pointed out in detail in a paper on the subject, published by Mr. Varley, in the fifty-first volume of the *Transactions of the Society of Arts.* The eye-piece in question was invented by Huyghens, for telescopes, with no other view than that of diminishing the spherical aberration, by producing the refractions at two glasses instead of one, and of increasing the field of view. It consists of two plano-convex lenses, with their plane sides towards the eye, and placed at a distance apart equal to half the sum of their focal lengths, with a stop or diaphragm placed midway between the lenses. Huyghens was not aware of the value of his eye-piece; it was reserved for Boscovich to point out that he had by this important arrangement accidentally corrected a great part of the chromatic aberration. Let fig. 53 represent the Huyghenian eye-piece of a microscope, F F being the field-glass, and E E the eye-glass, and L M N the two extreme rays of each of the three pencils, emanating from

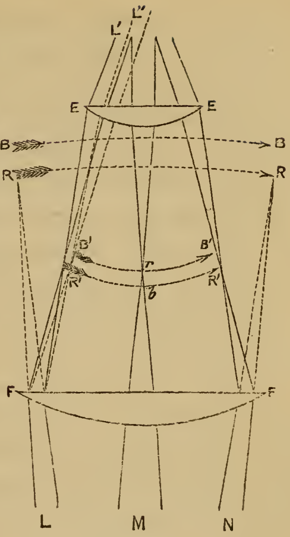

FIG. 53.

the centre and ends of the object; of which, but for the field-glass, a series of coloured images would be formed from R R to B B; those near R R being red, those near B B blue, and the intermediate ones green, yellow, and so on, corresponding with the colours of the prismatic spectrum. This order of colours, it will be observed, is the reverse of that described in treating of the common compound microscope, fig. 51, in which the single object-glass projected the red image beyond the blue. The effect just described of projecting the blue image beyond the red, is purposely produced for reasons presently to be given, and is called over-correcting the object-glass as to colour. It is to be observed also, that the images B B and R R are curved in the wrong direction to be distinctly seen by a convex eye-lens, and this is a further defect of the compound microscope of two lenses. But the field-glass, at the same time that it bends the rays and converges them to foci at B' B' and R' R', also reverses the curvature of the images as there shown, and gives them the form best adapted for distinct vision by the eye-glass E E. The field-glass has at the same time brought the blue and red images closer together, so that they are adapted to pass uncoloured through the eye-glass. To render this important point more intelligible, let it be supposed that the object-glass had not been over-corrected, that it had been perfectly achromatic; the rays would then have become coloured as soon as they had passed the field-glass; the blue rays to take the central pencil, for example, would converge at *b*, and the red rays at *r*, which is just the reverse of what the eye-lens requires; for as its blue focus is also shorter than its red, it would demand rather that the blue image should be at *r*, and the red at *b*. This effect we have shown to be produced by the over-correction of the object-glass, which protrudes the blue foci B B as much beyond the red foci R R as the sum of the distances between the red and blue foci of the field-lens and eye-lens; so that the separation B R is exactly taken up in passing through those two lenses, and the whole of the colours coincide as to focal distance as soon as the rays have passed the eye-lens. But while they coincide as to distance, they differ in another respect; the blue images are rendered smaller than the red by the superior refractive power of the field-glass upon the blue rays. In tracing the pencil L, for instance, it will be noticed, that after passing the field-glass two sets of lines are drawn, one whole and one dotted, the former representing the red, and the latter the blue rays. This is the accidental effect in the Huyghenian eye-piece pointed out by Boscovich. The separation into colours of the field-glass is like the over-correction of the object-glass; it leads to a subsequent complete correction. For if the different-coloured rays were kept together till they reached the eye-glass, they would then become coloured and present coloured images to the eye; but, fortunately, and most beautifully, the separation effected by the field-glass causes the blue rays to fall so much near the centre of the eye-glass, where, owing to the spherical figure, the refractive power is less than at the margin, that the spherical error of the eye-lens constitutes a nearly perfect balance to the chromatic dispersion of the field lens, and the red and blue rays L′ and L″ emerge sensibly parallel, presenting in consequence the perfect definition of a single point to the eye. The same reasoning is true of the intermediate colours and of the other pencils*.

Telescope.—There are many forms of telescope; it, however, will be sufficient for the purposes of illustration to select diagrams of the section of two of these instruments. These will show the two principles upon which all are constructed—the dioptric or refracting, and the catoptric or reflecting telescope.

Fig. 54 is a section of the astronomical telescope; it consists of two lenses, A B and C D; the first being the object-glass, the second the

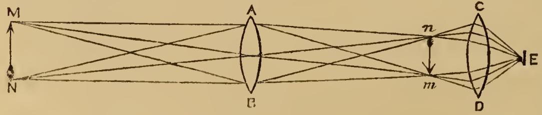

FIG. 54.

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* Ross on the Microscope, in Penny Cyclopedia.

eye-glass; A B is a lens with a long focal length, the eye-glass is one of a short focal length. From a distant object M N, an inverted image is formed at *m n*, in the focus of the object-glass, this inverted image being magnified by the eye-lens, so that a greatly enlarged picture reaches the eye E. If the object be near to the telescope, the rays from it will be diverging, and the image will recede from the lens A B, consequently the tube in which the eye-lens is placed must be drawn out. On the contrary, if the object be distant, then the rays will be more nearly parallel, and consequently form an image near to the object-lens; the eye-lens must then be carried near to it, or no distinct picture will be formed upon the eye.

When objects require to be seen erect, two additional lenses are added, by which the inverted image is made to enter the eye in an erect position. The instrument then constitutes the terrestrial telescope, and is shown in fig. 55, as used for land objects; which, it will be seen, is the same as fig. 54, with the addition of two other lenses E F, G H, which have the same focal length as C D, and are placed at distances equal to double their common focal length. In this telescope the progress of the rays is exactly the same as in the astronomical one as far as L, where the two pencils of parallel rays C L, D L, cross in the anterior focus of the second eye-glass E F. These rays, falling on E F, form in its principal focus an erect image *m′ n′*, which is seen erect by the third eye-glass G H; as the rays diverging from *m′ n′* in the focus of G H enter the eye in parallel pencils at J. When the eye-glasses are equal, the magnifying power of these two telescopes is equal.

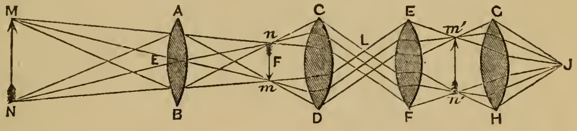

FIG. 55.

Of course, these instruments as here represented, and as formerly made, must be subject to all the defects arising from spherical and chromatic aberration mentioned as affecting the older forms of microscope. They are to be remedied by the same means, using the doublet object-glass and the Huyghean or Ramsden's achromatic eye-piece.

In the reflecting telescope the light, entering the open end of the tube, is reflected from a large concave speculum at the top, upon a small concave or convex speculum placed in front of the larger; the distance between the two being regulated by an adjusting screw. The image thus formed by the second reflection is magnified by an eye-piece fixed immediately behind the large speculum, by which an inverted image falls upon the eye. These forms of reflecting telescopes are the Gregorian and the Cassegrainian. Or, as represented in fig. 56, the smaller speculum may be placed at such an inclination to the axis of the large one, that the image is reflected to an aperture in the side of the instrument. This allows the larger speculum to be entire, not having an aperture in its centre as in the two former. It is the Newtonian telescope, and is the form of instrument adopted by Lord Rosse for his gigantic telescopes. In fig. 56, A B is a concave speculum upon which rays M N from a distant object, which enter the open end of the tube, fall. These are reflected, and form an inverted image, as *m n*. This image, *m n*, is reflected by the small plane speculum, placed at an angle of 45° to the side of the tube at *m′ n′*, so that it is magnified by the eye-piece E, and the rays enter the eye parallel.

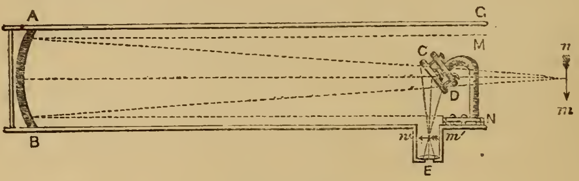

Fig. 56.

CHAPTER IV.

ON THE STRUCTURE OF THE HUMAN EYE AND ITS APPENDAGES.

In describing the organ of sight, two different methods may be pursued. The perfect organ, as found in man, may be examined, and after becoming acquainted with its different parts, the variations and modifications found in other creatures may be studied; or we may start with the simplest eye-dot to be found, and gradually trace upwards the successive additions through its gradually advancing chain until we arrive at the most complex dioptrical instrument. Both plans present advantages and disadvantages. The latter is probably to be regarded as the more scientific, but it is only fitted for the zealous student of comparative anatomy and physiology; it moreover presupposes some considerable acquaintance with the subject, or reference would be constantly made to parts, the existence of which the reader would be ignorant of. Hence a description of the more complex organ appears to be the best adapted for a plan like the present, where the aim principally is to instruct the student in human anatomy. With it, therefore, we shall first proceed; the most important modifications found in different animals, to adapt it to their peculiar habits, will afterwards be alluded to; but as the minute structure of the different tissues must be here described, so much of the microscopic anatomy of their eyes as is deemed necessary for elucidating the subject will be introduced with that of man.

The organ of sight consists of a nearly spherical ball—the globe of the eye; and of various accessory structures, by which this is maintained in a state of healthful action—the appendages. Of the globe only the anterior portion is at all exposed, the greater portion of it being contained within the orbit, where it lies embedded upon a soft cushion of fat, surrounded by muscles, blood-vessels, and nerves. The essential parts of the apparatus consist of a sensitive, thin, membraniform, concave disk, continuous with, and in part produced by, the expanded fibres of the optic nerve, upon which membrane the images of external objects are painted; and a transparent complex optical apparatus placed before it, for the purpose of refracting the rays of light to a focus upon it. The primary cause of the globular form of the eye is obviously a physical one, that the retina may in every part be preserved equidistant, or nearly so, from the crystalline lens, and thus accurately receive the rays of light when in focus.

The APPENDAGES of the eye are naturally divisible into those which are for the purpose of lodging and protecting it, and those by which it is maintained in a fit condition for action. The first consists of the *orbits, the eyebrows, the eyelids, and the lachrymal apparatus.* The second of the *muscles, the blood-vessels, and the nerves.* In this order their description may be taken, reserving that of the globe itself until they have been described.

The ORBITS are two pyramidal cavities of an irregular quadrilateral figure, having their bases directed forward and outward, and their apices backwards and inwards; so that if these were prolonged somewhat farther backwards, they would meet together at the centre of the posterior clinoidal processes of the sphenoid bone. The outer or temporal side of the base does not project nearly so far forward as the nasal or inner, by which arrangement a much wider lateral field of vision is obtained. Seven bones enter into the composition of each orbit; the frontal, sphenoid, ethmoid, inferior maxillary, malar, palate, and unguis: but as the first three are common to both orbits, there are only eleven bones in the two. The roof is concave, formed by the orbitar plate of the frontal bone and the lesser wing of the sphenoid; in the root of which, nearly at the apex of the orbit, but a little to its inner side, is the circular optic foramen, which gives passage to the optic nerve and ophthalmic artery. On its inner and anterior part, is a roughness or spicula for the attachment of the pulley of the superior oblique muscle; and at its outer, just within the margin of the orbit and outer angular process of the frontal bone, is a decided depression, which lodges the lachrymal gland; while between the two, but nearer to the former, is a foramen or notch, for transmitting the supra-orbital artery and branch of the fifth pair of nerves. The floor forms the roof of the antrum, and is formed by the orbital plates of the superior maxillary, malar, and palate bones. It is inclined downwards and outwards. Posteriorly there is a groove, which runs horizontally forwards to terminate in the infra-orbital canal, transmitting the artery and nerve of the same name; on its inner and anterior part, outside the lachrymal canal, is a slight roughness, for the attachment of the inferior oblique muscle. The inner wall is shorter than any of the others, and is directed backwards, being parallel with the corresponding wall of the other orbit. The unguis, ethmoid, and sphenoid bones form its line; the nasal process of the maxillary is not unfrequently described as forming part of the inner wall, but incorrectly so; as it only enters into the boundary or base of the orbit, being separated from the wall itself by the large lachrymal canal, which is formed by this process anteriorly, and the ungual bone posteriorly; inferiorly where it terminates in the nostril, this canal is completed by the inferior spongy bone. At the juncture of this wall with the upper are two foramina, the anterior and posterior ethmoidal; the former giving passage to the nasal nerve and a small artery, the latter to the ethmoidal artery. The outer wall of the orbit is formed by the malar and sphenoid bones; it is longer and more sloping inwards than any of the others, so that the pyramidal form of the orbit is in a great degree caused by the obliquity and triangular form of this wall. It contains some small foramina, through which junctions are formed between branches of the fifth and seventh pair of nerves. At the posterior part of the superior external angle, there is a large fissure between the two wings of the sphenoid bone—the foramen lacerum orbitale superius; this fissure runs from within, outwards and upwards, and is broader internally than externally,—it gives passage to the third, fourth, first division of the fifth, and sixth nerves, and also to the ophthalmic vein. Communicating with this fissure, but running forwards and outwards, is another large fissure, wider at its extremities than at its middle part, passing forwards and outwards towards the inferior external angle—the spheno-maxillary fissure, or foramen orbitale inferiorius. This separates the malar and sphenoid bones from the maxillary and palate bones; it is filled with fat, and gives passage to the infra-orbital nerve and blood-vessels. At the junction of the orbital and nasal processes of the maxillary bone, at the inner side of the base of the orbit, just outside the lachrymal canal, there is an irregularity, which not unfrequently may be felt during life through the skin; it forms an useful guide in opening the lachrymal sac, which is placed at its inner side. Fig. 57 will show the general form of the orbit.

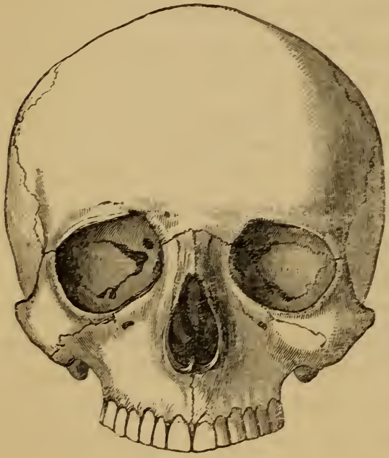

FIG. 57.

The EYEBROWS are the two arched ridges which extend over the eyes, forming the boundary between the edge of the orbit and the forehead. Each brow consists of thick dense skin, with some fat, united closely with muscular fibres beneath it. In this skin grow a great number of short stiff hairs, which are directed from within outwards, and overlap each other, like straw in a thatch, particularly at the inner extremity, near the root of the nose, where the two brows nearly (and in many persons quite) unite; they are freely supplied with blood, and possess considerable sensibility.

Man is the only creature who possesses eyebrows; their use is twofold. First, they in a remarkable degree assist in giving character and expression to the countenance; their motions are of great value in exhibiting the various stronger passions. The depressed and contracted brows of wrath, hatred, and revenge, contrast strongly with the elevated brows of wonder and amazement. Their second use, in affording protection to the eye, is important. By their arched form they materially tend to prevent foreign particles from entering the eye; thus, wet or perspiration streaming down the forehead is carried to the side of the orbit. By the sensitiveness of the nerves at the bulbs of the hairs, they serve as feelers, and warn us of the approach of extraneous matter. By contracting and depressing the brows, we are enabled materially to lessen the quantity of light admitted to the eye, as everybody is at once conscious of when placed in a dazzling light. The prominence of the brow is in part produced by the superciliary ridge of the frontal bone, and in part by the three muscles which move it. These are the orbicularis palpebrarum, the corrugator supercilii, and the occipito-frontalis; by the former the brows are depressed and contracted, and the skin of the forehead wrinkled in a vertical direction; but this motion is more particularly caused by the corrugator, which is attached to the nasal process of the frontal bone, and coursing upwards and outwards is lost in the structure of the brow, where the fibres become commingled with those of the orbicularis and the occipito frontalis muscles. The last-named muscle is the opponent of the corrugator, elevating the brows, and wrinkling the forehead in a transverse direction. Figs. 58, 59, and 60 show the form and position of the eyebrows and lids; the first is a profile view of the left eye of an adult man, the second a front view of the same eye opened, and the third of the same eye closed.*

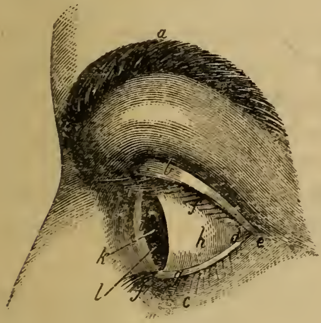

FIG. 58.

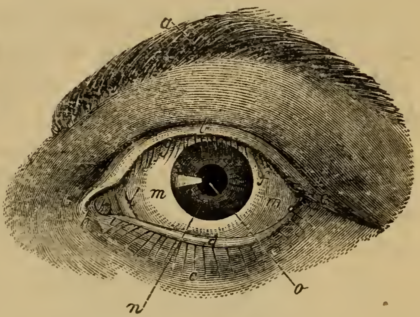

FIG. 59.

The EYELIDS are two thin, membraneous, moveable curtains placed before each eye; at first sight they appear to be very simple structures, but a careful examination shows many tissues entering into their composition. The upper is considerably the larger of the two; so that, when closed, the fissure is decidedly below the axis of vision, and the eye is thus more completely shielded from light than if the fissure were in the centre, as fig. 60 shows. They are composed of skin, orbicular muscle, tarsal cartilage, meibomian glands, conjunctiva; and, in the upper lid, of the levator muscle. The skin is continuous with that of the face; it has become very delicate, thin, and almost free from fat, which is so abundant under it in the face. This is a simple but important modification; for were it not so, and the lids became loaded with adeps, as other parts of the face in fat people, the result would be blindness from inability to open the eyelids; the cellular texture is loose, hence the readiness with which serum is here effused. At the edges of the lids the skin is extremely thin, adheres very closely to the tarsal cartilage, over which it is reflected, and becomes modified into conjunctival membrane; it lies immediately upon the orbicular muscle, to which it is intimately attached, and thus is readily moved by it.

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* Figs. 58, 59, 60. *a*, eyebrows; *b*, superior eyelid; *c*, the inferior; *d*, external canthus; *e*, external commissure of the lids; *f*, the eyelashes; *g*, free edge of the lids; *h*, the internal commissure; *i*, the internal canthus; *k*, caruncula lachrymalis; *l*, the plica semilunaris; *m*, sclerotic; *n*, cornea; *p*, pupil.

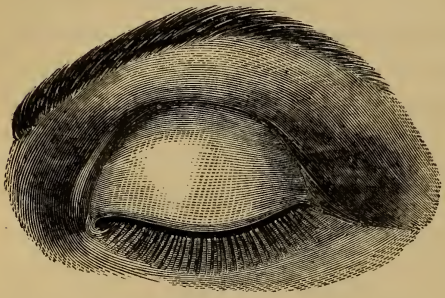
Fig. 60.

The *orbicularis palpebrarum* is a large, flat, thin muscle of an almost circular form, the fibres coursing from the inner angle of the eye to the outer, extending over the lower part of the forehead above, and the upper part of the muscles of the cheek below. They are attached to the internal angular process of the frontal bone, and to the upper edge of the *tendo oculi*, from whence they proceed outwards in the upper lid, course round the external angle of the eye, and, returning along the lower lid and cheek, are attached to the lower edge of the tendo oculi, and to the nasal process of the superior maxillary bone: a few of the fibres decussate at the outer angle, and are lost in the skin, or attached to the bone, but only in a slight degree; hence its fixed point of action is the internal angle of the eye. It lies immediately upon the tarsal cartilages, the palpebral ligaments, and, in the upper eye, the levator muscle. The circumferential fibres are stronger and red, the middle fibres pale and less distinct, while those which are close to the edge of the lids, though pale, are more distinct; hence by some anatomists it has been proposed to separate the muscle into two or more, which, however, does not appear to be necessary.

The action of this muscle will be to close the lids by raising the lower, and depressing the upper, at the same time drawing both, more especially when in strong action, inwards. The tendon of this muscle—the *tendo palpebrarum*, *tendo oculi*—is a small tendon about the one-sixth of an inch long, extending from the upper part of the nasal process of the superior maxillary bone to the inner canthus of the eye, where it divides into two portions, which pass to the tarsal cartilages, upon which they become expanded, and at the outer ends of these the fibres pass to the external angle of the eye, to be lost in the periosteum of the malar bone. The tendon is rendered much more conspicuous by drawing the lids outwards; it passes over the lachrymal sac, to which it gives a thin fibrous covering. It forms a guide in opening the sac in case of fistula lachrymalis.

Immediately under this tendon, and passing from near the two lachrymal puncta, over the sac, to be attached to the ridge of the lachrymal bone, are sometimes seen a very few indistinct fibres, which have been described as a separate

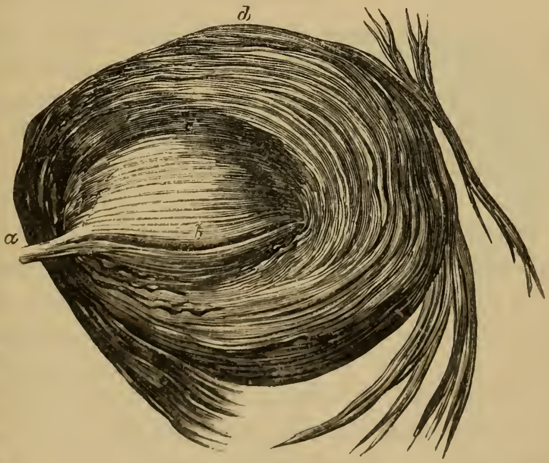

Fig. 61.

Fig. 61. Orbicular muscle:—*a*, tendo palpebrarum; *b*, fibres in close contact with the edge of tarsal cartilage, *orb: ciliaris*; *c*, middle fibres in the lid; *d*, stronger fibres passing on the forehead and cheek, *orb: latus*.

muscle—*tensor tarsi,* from its supposed action. It is often not very easy to be seen, and it appears properly to belong to the orbicular muscle, with which formerly it was associated.

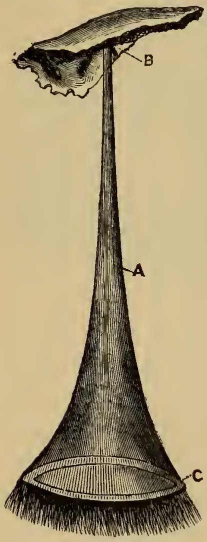

Fig. 62.

In the upper lid there is the *levator palpebræ superioris,* a long delicate muscle, which arising narrow from the apex of the orbit above the optic foramen, passes out over the superior straight ocular muscle, and beneath the periosteum and the fourth and supra-orbital nerves; it expands into a broad membrane, which encloses, and is lost upon the tarsal cartilage, having the conjunctiva upon its inner surface, and the palpebral ligaments and orbicularis on its outer.

The *tarsal cartilages* are the parts which give firmness and stability to the lids, and form their free thick borders; they answer the same purpose as the cane or wire does in the boy's kite, without which the paper would collapse and fall into folds. In the lower lid the cartilage is a narrow slip; in the upper it is larger, and semi-lunar in shape. Both are attached to the edge of the orbit by a continuation of the periosteum from its margin, constituting what is sometimes called the *palpebral ligaments,* which cover the portions of cartilage, and at their ends the fibres become thicker, and closely connect them with the orbit, forming the tarsal ligaments or tendons of the lids. This is especially the case at the inner angle of the eye, where the fibres become mingled with the tendo palpebrarum, and in fact may be said to form it. The cartilages are sometimes described as fibro-cartilage; they contain some true cartilage cells; they do not extend the whole length of the eyelid, the inner sixth part being wanting, where the lids are separated from each other, as though a piece were cut out; the caruncula lachrymalis is there placed. Upon the outer edge of the free margin of each lid are two or three rows of strong hairs—the *ciliæ* or *eyelashes.* These hairs are stronger and larger in the

Fig. 62. Levator palpebræ superioris:—A, muscle; B, apex of orbit; C, eye-lid. See also Fig. 75.

upper than in the lower lid; the hairs in the two lids are curved in opposite directions. In the upper lid they form a convexity looking downwards and forwards; and in the lower, upwards and inwards; from which arrangement they are enabled to protect the eye-ball without the lids themselves being altogether closed. The eye-lashes are of great importance, not merely as an ornament to the face, but they assist in excluding the light when too strong, and they are delicate organs of touch; their bulbs being freely supplied with nerves from the fifth pair, they give warning of the approach of small foreign particles of dust, insects, &c., and thus most materially protect the eye-ball.

The thick free edges of the tarsal cartilages are not perfectly square. The ocular is slightly bevelled off; so that when the lids are closed, only the outer edges come into contact, and thus a small channel is left between them and the anterior surface of the eye-ball, along which it is supposed by many that the tears flow during sleep. Near their inner extremity is a minute conical elevation—the *papilla lachrymalis,* in which there is a minute aperture, the *punctum lachrymale.* According to the length of these tarsal cartilages is the extent of the fissure of the eye, which varies much in different people; giving rise, often without variation in the size of the ball, to the appearance of large or small eyes, which greatly depends upon the extent to which the lids are separated. This fissure, with the free edges of the lid everted, is shown in fig. 63.

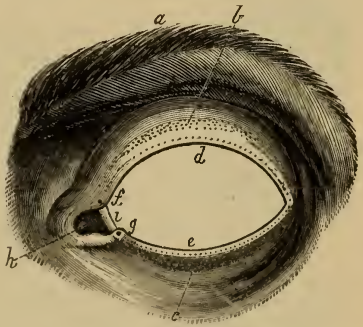

Fig. 63.

Lying in vertical rows in grooves on the inner surface of each tarsal cartilage, and immediately beneath the conjunctiva, are from twenty-six to thirty-six vermicular-looking lines, the

Fig. 63. The fissure of the eye-lids widely opened, and somewhat everted. *a*, the brow; *b*, the apertures of the cilia of the upper lid; *c*, those for the lower; *d e*, the apertures of the Meibomian glands in the upper and lower lids; *f g*, the two puncta lachrymalia; *h*, the caruncula lachrymalis; *i*, the *plica semilunaris.*

Meibomian glands, or sebaceous follicles, fig. 64. They are more numerous in the upper than in the lower lid; each follicle consists of a narrow tube with numerous cæcal pouches. They are mucous follicles formed by a prolongation of the conjunctival membrane covered with epithelium; they secrete a thick sebaceous matter, which escapes by as many minute ducts as there are follicles, opening on the inner surface of the cartilages. In a state of health this secretion is not very obvious; but when the eye-lids or conjunctiva are inflamed, or have been irritated by exposure to strong sun-light, or wind, or dust, it may often be found adhering to the eye-lashes on awaking the following morning, and in some affections it is poured out abundantly.

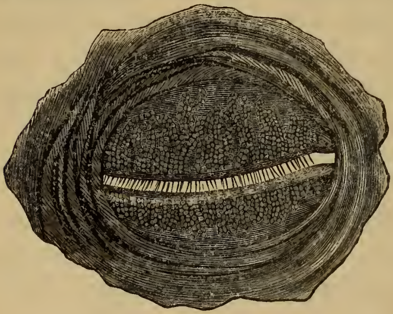

Fig. 64.

The secretion, doubtless, serves to lubricate the lids, and thus prevent friction in their constant motions over the surface of the eye-ball, as in winking. By some the secretion is thought, by its waxy character, to prevent the falling of tears over the lids upon the cheeks. Figs. 64, 65, and 66, show the situation and structure of these follicles.

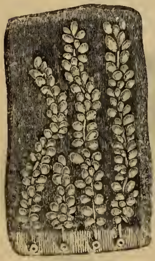

Fig. 65.

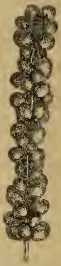

Fig. 66.

The eye-lids are very freely supplied with nerves and blood-vessels; the former are derived principally from branches of the first division of the fifth pair of nerves, as will be more particularly described; from some of

Fig. 64. The inner surface of the two eye-lids, showing the position and number of the Meibomian glands in the two lids.

Fig. 65. Four of these glands magnified, with their orifices upon the tarsal cartilage.

Fig. 66. A single gland still more magnified, to show the cæcal pouches.

Fig. 67 shows the nerves of the lids, seen from their inner surface.

Fig. 68 shows the arteries of the lids, the surrounding arteries with which they inosculate, and also the arteries of the ocular conjunctiva.

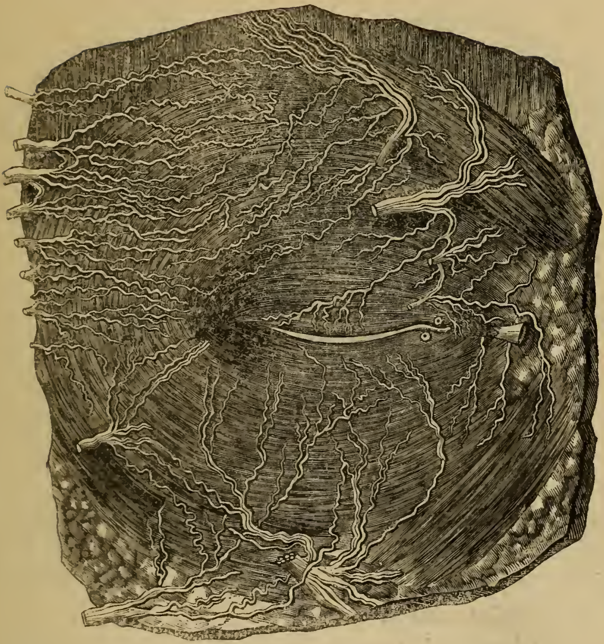

FIG. 67.

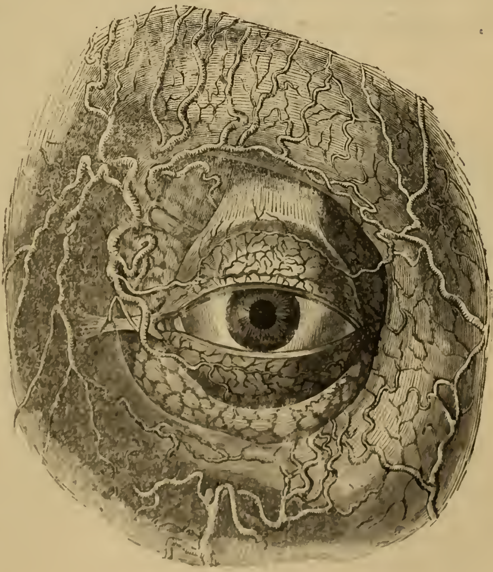

FIG. 68.

the infra-orbital branches of the second division of the same nerve, and from small branches of the facial portion of the seventh pair. The arteries are derived from small branches of the ophthalmic artery, which inosculate freely with divisions of the infra-orbital, temporal, and facial arteries. The veins

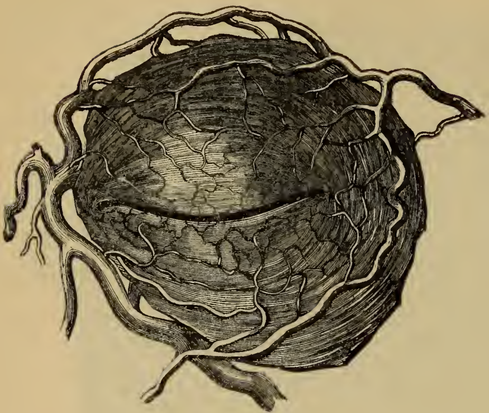

Fig. 69.

have, in course and connexion, a general correspondence with the arteries. Figs. 67, 68, and 69 will show these.

Conjunctiva.—The skin of the eye-lid does not terminate abruptly, but at the insertion of the eye-lashes it becomes continuous with, in fact, converted into, the mucous membrane, which, after lining the lids, is from them reflected upon the sclerotic coat, the anterior third of which it covers, and the entire cornea; hence, from its connecting the lids with the ball of the eye, it is named the *membrana conjunctiva*, or *tunica adnata.*

It may be described, though perfectly continuous, as consisting of two portions, the palpebral and the ocular. The palpebral is thicker and denser than the ocular; it is highly sensitive and vascular (plate 1), becoming, on the slightest irritation, one mass of vessels. It has upon its surface numerous papillæ like those of the cutis; these are smaller and arranged more regularly in lines near the tarsus than on the lids, fig. 70. In structure it consists of a thin layer of connective tissue in which yellow fibrous tissue is very apparent, and a dense layer of epithelial cells, as shown in plate 1. As it approaches the eye-ball it loses its papillary structure, becomes

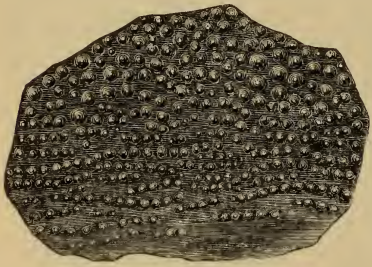

Fig. 70.

Fig. 69 shows the veins of the eye-lids. These three figures are sufficiently explicit to those who have dissected, without any lengthened reference (after Arnold).

Fig. 70 is a magnified view of the palpebral conjunctiva, to show its papillæ as arranged near the tarsal edge in curved lines, and smaller than over the lid, where they are more irregular, as well as larger.

less dense and vascular, is less closely connected with the lid, and is reflected upon the sclerotic coat, to which it is loosely connected by an abundant elastic submucous tissue, where it is whiter and much less vascular. The vessels are a few larger meandering branches continuous with those of the palpebral portion, and a number of smaller and straighter, which are derived from the muscular and anterior ciliary branches of the ophthalmic artery; they run to the margin of the cornea, where most of them form loops, and terminate by communicating with each other, some few very possibly passing on over this structure, but in health of so small a size as not to admit of red globules.

Many anatomists, however, deny that any vessels do so pass; but inasmuch as in the fœtus no one can doubt their existence, and in a state of inflammation or long-continued irritation, vessels conveying red blood do pass upon the cornea, and are distinctly continuous with the sclerotic conjunctival vessels, I believe in their presence in the normal condition, otherwise we must admit that blood-vessels are formed, *de novo,* with remarkable facility, which appears less probable than the dilatation of vessels already existing, which we know does take place in other tissues when inflamed or irritated. At the margin of the cornea the conjunctiva is very closely connected with it, and becomes so thin and transparent as to be with difficulty by the naked eye alone traced, hence its continuation has been frequently denied; though the diseases to which the cornea is liable, and the fact, as pointed out by Bichat, that under some circumstances of putrefaction a continuous layer may be raised from the cornea, and that in those animals who periodically cast the epidermis a layer is thrown off the cornea at the same time, left little doubt as to its existence; this the microscrope has determined, for with it there is no difficulty in tracing at least three or four layers of pavement epithelial scales, the innermost of which are crowded together and stand vertically, while the more superficial layers are flattened and overlap each other (see plate 1). They appear to be formed on, and to be connected to the proper corneal structure by an extremely delicate layer of connective tissue, or basement membrane, in which I believe the minute colourless blood-vessels lie. In some animals, the haddock, for instance, where the conjunctiva is clearly seen as a modification of the skin passing over the true cornea, I have found carried to some distance over the edge of the cornea some of the cutaneous stellate pigment cells, and in old cases of staphyloma, when the cornea is white and opaque, particularly after destructive purulent ophthalmia, by which the cornea becomes very thick, the increase is in a great measure made up of an augmentation of the number of these epithelial cells. Not merely does the conjunctiva cover every part of the exposed anterior portion of the eye, but it sends prolongations into all the ducts and apertures here formed; indeed, it appears to form them in a great degree. Thus at the tarsal cartilages it passes into all the Meibomian follicles; at the two lachrymal puncta it enters, lines the duct and sac, and passes through them, to be continuous with the Schniderian membrane. Under the upper lid, it passes into the ducts of the lachrymal gland.

At the inner canthus, called the *lacus lachrymarium,* it gives rise to the *caruncula lachrymalis* and the *plica semilunaris.* The caruncula is a small red fleshy-looking body, consisting of mucous glands formed by lacunæ in the conjunctiva, and having a few fine hairs growing upon it. The plica is a crescenticfold of membrane, stretching outwards over the sclerotic. The caruncula is supposed, besides secreting a little mucus, to assist in directing the tears into the puncta, and the plica to allow of a greater freedom of motion of the globe in an outward direction; but these are problematical, and I apprehend that in man these structures should rather be regarded as mere vestiges of the third eye-lid and large accompanying gland which are found in many animals, figs. 63 and 73.

Lachrymal Apparatus.—The lachrymal organs consist of the gland which secretes the tears, and the apparatus which acts as a waste pipe, carrying away the tears into the nose. The object being to keep the cornea constantly moist and clean by the removal of all small foreign particles, which are constantly settling upon it, as upon every other surface, and of obviating the desiccating effect of the air,—functions of the most essential importance. The *gland* somewhat resembles in size and form the half of a walnut; it is covered by an imperfect capsule of connective tissue, by which its lobules are held together, and by which it is connected to contiguous parts, and held in its situation. It rests upon the upper and outer part of the eye-ball, being in contact with the superior and outer straight muscles; it is lodged in the hollow of the orbital plate of the frontal bone, to which it adheres, fig. 72. The conjunctiva is in contact with its anterior edge; in shape it corresponds with the part with which it is in contact, being concave within and convex without; there is a fissure running along it, by which it is partially divided; hence some anatomists speak of it as consisting of two lobes.

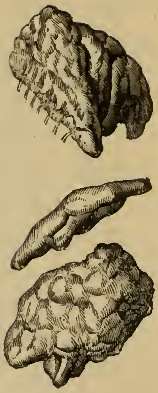

Fig. 71.

Its structure is made up of an aggregation of granular masses, which, when traced to their minute organization, are seen to consist of a number of follicles communicating with and connected together by tubes. The outer walls of these are formed of delicate connective tissue, and the inner of mucous membrane, lined by cylindrical epithelium, which is continuous with the conjunctiva. The tubes open one into another, and ultimately form from six to ten very small ducts, about three lines long, which open through the conjunctiva, at the upper and outer part of its ocular surface; in man these are so small as to be with difficulty seen, but in almost any of the larger quadrupeds they are easily to be detected. The gland is freely supplied with a branch from the ophthalmic division of the fifth pair of nerves, and with blood by a branch of the ophthalmic artery.

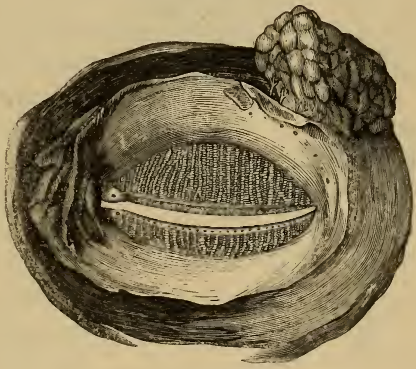

Fig. 72.

Fig. 71 gives three views of the lachrymal gland, with its excreting ducts shown in one of them.

Fig. 72 shows the position of the gland and conjunctiva, with the aperture of the ducts, and the Meibomian glands.

The ducts for the escape of the tears being situated at the inner angle of the eye, the tears have to pass over the surface of the eye; this they will to some extent do by their own gravity, but, by the constant action of the orbicularis muscle, they are diffused over its entire surface, washing all small particles towards the inner canthus, where the tears are absorbed by the puncta and carried through the sac into the nose; the foreign particles generally resting at the lacus lachrymarum. The *lachrymal canals* commence in the two small *puncta,* one of which is placed in the centre of the conical papilla near the inner termination of each tarsal cartilage. The upper canal is slightly the smaller and longer of the two; it at first ascends, then bends at the right angle and passes nearly horizontally, but with an inclination downwards, and opens into the lachrymal sac. The lower canal at first passes directly downwards, then bends at a right angle, and passes horizontally inwards to join the upper before opening into the sac, or to pass into it by a separate opening. Anatomists differ as to which is the normal condition, probably the one is as frequent as the other. They are exceeding small tubes, except at the angles they make where they are sensibly dilated, figs. 73 and 75.

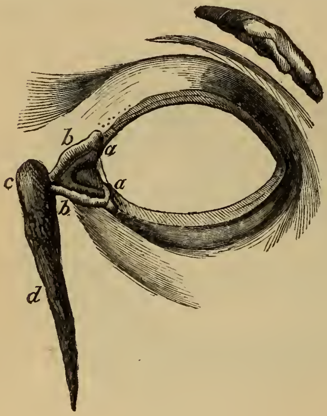

Fig. 73.

The *lachrymal sac* and *nasal duct* form but one canal, the sac being the upper dilated portion, the canal that portion which is lodged in the channel formed by the ungual, superior maxillary and inferior spongy bones. The upper end of the sac is rounded and closed; it rises about two lines above the tendo oculi, which crosses it where the canals enter it. It is covered by the skin and orbicular muscle, on its inner side and behind it has the ungual bone, on its outer the caruncula, and the origin of the inferior oblique muscle of the eye; it is from one

Fig. 73 shows the lachrymal puncta *a a*, the canals *b b*, the sac *c*, and nasal duct *d*; in connexion with the lids and the gland *in situ*.

and quarter to one and half inch long, from its upper round end to its opening near the middle of the outer wall of the lower chamber of the nose. It is fusiform in shape, and passes in a direction downwards and slightly outwards and backwards. Its opening into the nose is not very perceptible, from the membrane being thrown into a fold, which forms an imperfect valve. The walls consist of an outer, thin, but firm and strong fibrous coat, by which it is connected with the bones, and which is, if not derived from, at least connected and continued with the layer from the tendo oculi and the periosteum; and an inner follicular mucous lining derived from the conjunctiva, and by which the mucous membranes of nose and eye are united. There is an epithelium which in the lachrymal canals, Kolliker says, is of the squamous kind; but in the sac and duct as in the nares is furnished with vibratile cilia. There is an imperfect contraction a little above the middle of the canal, which divides the lachrymal sac from the nasal duct.

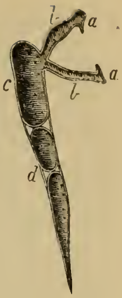

Fig. 74.

The ACCESSARY ORGANS which are lodged deeply within the orbit are, the muscles, the blood-vessels, and the nerves. These are not exhibited without considerable labour and much care, in consequence of their number and minuteness, and from their being imbedded in a large quantity of adipose and cellular tissue. The adipose tissue is most abundant towards the back part of the orbit, where it is collected into large, loose, globular or oval fat-cells; in which there is comparatively little connective tissue, the fat being more oil-like than in many other parts of the body. It surrounds the optic nerve and the globe of the eye, which it separates from the muscles and forms a soft cushion for the equable support of the globe, while it is so yielding as not to present the least impediment to its various movements, so that no strain is ever put upon the ball, nor is there any danger of its spherical form being in the least degree disturbed either by want of due support, or by undue pressure upon any point; and further, as the support to the eye-ball is entirely of a physical character, there is no tension or fatigue of the muscles, as

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Fig. 74, the same parts separate and laid open to show the mucous surface; the letters of reference are the same as in last.

would necessarily happen were the eye suspended or maintained *in situ* by them. Thus the least contraction of the muscles suffices to produce a change in the direction of the eye. The advantage of this mode of support and the extreme delicacy of motion by a very slight force may be seen by suspending a ball in any fluid of nearly the same specific gravity as itself, the least agitation in the fluid is perceptible by its effects upon the ball ; or by watching the motions of a fish as it lies basking in the sun, or dashes away from an enemy.

Muscles.—within the orbit are seven muscles, six of which belong to the eye-ball ; the seventh, the levator palpebræ superioris, has already been described ; of course, if the few fibres on the lachrymal sac are considered as constituting a distinct muscle, the *tensor tarsi,* then eight orbital muscles must be enumerated. These muscles, with the exception of the inferior oblique muscle, have a common origin from the apex of the orbit, and proceed forward towards its base. Of the six ocular muscles, four are the recti or straight muscles, and two the oblique. The straight muscles are distinguished by their position as superior, inferior, internal, and external ; by their action, as *attollens, depressor abductor, and abductor* oculi ; and also by the physiognomical expression their action is supposed to indicate, as *superbus, humilis, bibitorius,* and *iracundus or indignabundus.* The straight muscles have almost a common origin from near the optic foramen, surrounding the entrance of the optic nerve. The rectus superior arises in common with the levator of the upper lid immediately above the optic nerve ; the other three, internus, inferior, and externus, by a common origin from the other portions of the foramen opticum, and

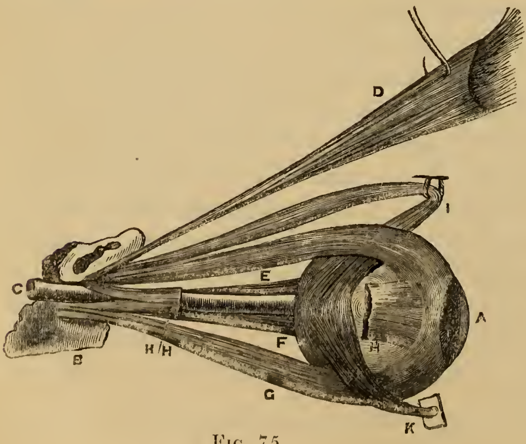

Fig. 75.

the externus from the edge of the sphenoid fissure as well; the third, sixth, and nasal branch of the fifth pair of nerves pass into the orbit between these two attachments. These four muscles then advance forwards; at first being very near to the optic nerve, but soon are separated by the fat before mentioned and the ciliary vessels and nerves; the superior directly above the eye, the inferior directly below in the vertical axis; the internus on the inner aspect, and externus on the outer, in the horizontal axis; at first they are narrow, with a few tendinous fibres, then broader and ribbon-like; they pass over the transverse diameter of the ball, where they expand into broad glistening tendons, which are inserted into the sclerotic coat about two or three lines from the cornea;* at this part many of these tendrinous fibres uniting together give rise to the brilliant glistening appearance of this part of the sclerotic seen through the conjunctiva, and formerly described as a distinct coat under the name of tunica albuginea.† The *obliquus superior* arises from the upper and inner side of the foramen opticum, between the superior and internal straight muscles, but not in common with them; it continues round and tapering, passing upwards, forwards, and inwards, along the wall of the orbit to the inner angle of the eye; where it ends in a fine round tendon, which turns round the small cartilaginous pully fixed for this purpose behind the internal angular process of the frontal bone; and becomes reflected at an acute angle, downwards, outwards, and backwards, passing above the inner, and under the upper recti muscles immediately over the ball, to be inserted by a broad thin tendon into the sclerotic coat, between the upper and outer

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* Sir E. Home described the tendinous fibres of the four recti muscles as being continued into the cornea, and there is a preparation of these parts made by him, and presented to the College of Surgeons of England, still in the museum illustrating this; but it is clearly artificial, and the result of dissecting up fibres of the sclerotic coat.

† Tunia tendinea was sometimes applied to it, the fibrous portion of the sclerotic conjunctiva being then called the tunia albuginea.

Fig. 75 represents the eye with its muscles in their natural position. A the ball of the eye, B the apex of the orbit, C the optic nerve, D the levator palpebræ superioris, E F G the upper, inner, and lower recti muscles, the outer H H having been cut away to show the position of the optic nerve and the insertion of the inferior oblique muscle H; I, the superior oblique muscle passing through its pully.

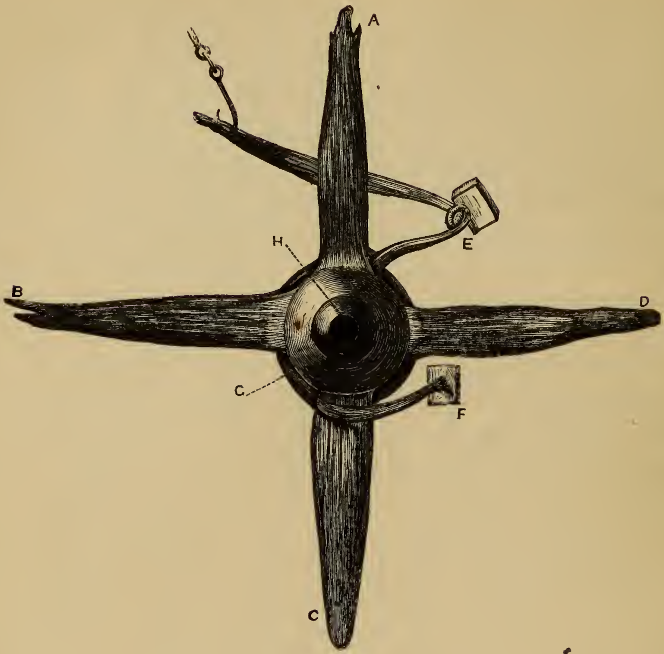

FIG. 76.

recti muscles, and behind the transverse diameter of the eye. As it passes over the pully, its motions are facilitated by the interposition of a small bursa mucosa. Fig. 76. The *obliquus inferior* is the smallest of the ocular muscles; it arises from the orbital edge of the superior maxillary bone, immediately external to the lachrymal sac, and as far outwards as the infra-orbital foramen; it is a comparatively broad muscle and passes backward, outward, and upwards, at first between the orbit and inferior straight muscle, then ascending between the ball of eye and the external straight muscle, it is inserted into the sclerotic coat very near to the attachment of the superior oblique, and, like it, posterior to the transverse axis of the ball.

Fig. 76. The same eye (the right) removed from the orbit, the straight muscles being separated from their attachment to its apex, and spread out to show how they are arranged round the ball or attached to the sclerotic coat. A the superior, B the internal, C the inferior, and D the external straight muscles; E the superior, and F the inferior oblique muscles, G the fore part of the sclerotic coat where the muscles are attached—the tunica albuginea or tendinosa, H the iris.

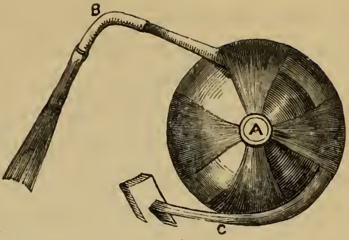

Fig. 77.

The four straight muscles, acting singly, are the direct opponents of each other. The superior turns the eye upwards, the inferior, downwards; the extenal pulls it outwards, and the internal, inwards; but if the four act together, the eye is directly retracted into the socket. If the muscles were inserted into or behind the transverse diameter of the eye, their effect would be simply to retract it; but in consequence of their passing over this, the first movement is to rotate the eye upon its axis; and when, as very often is the case, two adjoining muscles act together, they pull the eye in the diagonal between them, as, for instance, the superior and external muscles acting together will turn the eye upwards and outwards, and, by throwing a little more or less force into one or other of them, the eye may be moved more or less directly upwards or outwards. Thus, by only four muscles, arranged at the opposite radii of the globe, this may be moved in every direction of the circle; another most important consequence of this arrangement of the straight muscles will be, when acting in conjunction with the oblique muscles, somewhat to compress the eye and thus to lengthen its axis, as will hereafter be more particularly referred to.

Though the four straight muscles can rotate the eye, this motion is principally performed by the two oblique, which have sometimes been called the rotators of the eye, or *circumagentes* and *amatorii;* when acting singly, they will be opponents of each other. They will rotate the eye, but in opposite directions. The upper turns the eye downwards and onwards; the lower muscle, upwards and outwards; if acting in conjunction, their tendency would be to turn it outwards and pull it forwards; in the latter action opposing that of the straight muscles, which is to retract it.

There has been the greatest difference of opinion amongst

Fig. 77 also represents the right eye seen from behind; it shows how at first the four straight muscles closely surround the optic nerve A; B the superior oblique passing under the superior straight muscle, and C, the inferior oblique, passing under the inferior straight muscle.

anatomists as to the precise direction given to the eye-ball by the two oblique muscles, some describing their action as precisely opposite to that believed by other persons to be effected; but I think a careful consideration of the position and attachments of the two oblique muscles will show that the action is as above mentioned; for as muscles, when in action, must draw the moveable point of their attachment towards the more fixed, their action must be to draw that point of the sclerotic coat to which they are attached,—the superior muscle toward the upper and inner angle of the orbit,—the inferior muscle towards the inner and lower angle of the orbit; and as these points of attachment in the sclerotic are posterior to the transverse diameter, the ball, in moving, will rotate, and thus throw the cornea in the opposite direction; while, when the two muscles act together, as they pass on the opposite sides of the globe nearly to the same point of attachment, if the power of both be equal, the eye will be turned outwards, if unequal, and particularly if interrupted, the eye will rotate on its antero-posterior diameter as is so remarkably seen in the diseased condition called *Nystagmus.* To get over the difficulty felt as to their action some distinguished men (as Quain) have put forth the idea of the action of the oblique muscles being involuntary as opposed to the voluntary of the straight. I cannot but think this opinion is altogether erroneous, it is unsupported by any one fact, and it is quite opposed to the structure of the muscles and the sources from whence they derive their supply of nerves. On the same ground that the inferior oblique is supposed to act involuntarily at least four of the other muscles of the orbit ought to do so as the third pair of nerves supplies them all.

The opinion of the late Sir Charles Bell, that the function of the fourth pair of nerves is to induce a relaxed condition of the superior oblique muscle, in contradistinction to the ascertained action of every other motor nerve in the body, is most unsatisfactory and unphilosophical, and affords an illustration of how liable the most ingenious men are to err when having formed a theoretical opinion they are determined to make facts bend to it.

It is very curious to observe the connexion there is in the movement of the two eyes. They are consentaneous in their action; in health they move in concert, as one is directed so is the other. This so constantly and without any effort or even consciousness on our part occurs, (unless our attention be directed to it) that if one eye be closed or covered, still it will be found to move with the other, as that is directed to various objects. In their motions the two straight superior muscles act together, as also do the two inferior ; but the inner straight muscle of the left eye usually acts in concert with the outer straight muscle of the right; and the inner muscle of the right eye with the outer straight muscle of the left. The cause for this is obvious, were it not so, and the two outer or inner muscles acted together, the axes of the two eyes would never be in concert, either they would be turned inwards so as to produce a frightful squint, or they would be drawn outwards so as to diverge widely in opposition to each other, and thus cause a still more frightful stare. Yet at other times the two inner muscles must act in concert with each other, as when both eyes are turned to a very near object, we are then conscious of an effort, and that in proportion to the nearness of the object under examination. This consentaneous action of muscles, which more commonly do not act coordinately is a curious physiological fact; and, though the final cause of it,—to direct both eyes at the same time upon an object, so that the images may be formed upon corresponding points in the two retinæ or double vision would result, may be very apparent, the immediate means by which it is effected is not so evident. Perhaps the explanation may hereafter be found in the fact that the outer muscle of the eye is supplied by a separate nerve which does not send any branch to any other muscle, which of itself is indicative of some peculiar endowment in the outer muscle and its nerve.

Towards the anterior part of the orbit there is more cellular tissue than posteriorly, and from its being somewhat membraniform it has been sometimes spoken of as a fascia. The muscles arising from the apex of the orbit have investments of cellular sheaths, which, as the muscles advance, spread out, join together, and form an imperfect, thin, fasciform expansion over the anterior part of the sclerotic coat, immediately behind the conjunctiva, and passing behind it, near to the edge of the orbit, becomes continuous with the palpebral ligaments. This explains how in deep-seated suppuration in the orbit, the pus is sometimes confined and prevented from pointing externally, until much mischief and pain have been caused. This membrane is stronger and more fibrous on the inner side than the outer side of the orbit, being increased from the sheath of the superior oblique muscle, as it is reflected backwards over the pully. I have not unfrequently found in cases of strabismus this structure very strong and dense and thought it, rather than the inner straight muscle, was the cause of the inversion of the ball, and requiring free division, if a permanent cure is to be effected by operation.

This fascia is very much developed in the large quadrupeds where there is the strong circular suspensory muscle, which it separates from the recti, leaving well-marked apertures, through which these pass to their attachments.

ARTERIES. The globe of the eye, and most of its appendages, are supplied with blood by means of the *ophthalmic artery*, which is given off from the convexity of the internal carotid, by the side of the anterior clinoid process, just as the artery turns upwards to the brain, from the cavernous sinus. The ophthalmic artery here lies between the optic and third pair of nerves: it enters the orbit through the optic foramen on the lower and outer side of the optic nerve, to which it is closely attached by fibres from the dura mater. It then ascends over the nerve, and crossing to the inner side of the orbit, terminates at the internal angle of the eye by dividing into two branches. Its course is very tortuous; its branches are rather numerous than large, and though there is a general regularity in their distribution, yet the order and manner in which they arise from the trunk, as well as their number, is by no means uniform. They bear a considerable resemblance in their course to the distribution of the branches of the third and fifth nerves. Some very minute and long accounts of these vessels have been given but, inasmuch as there is considerable variation in most of the small branches, and it does not appear to signify in what particular order individual parts are supplied with blood, there does not seem to be any object gained by the attempt, which, however accurate in the particular case, will perhaps not be found to apply with strict exactness to any other dissections. The branches are commonly and properly divided into three sets.

1st. Those given off while the artery is on the outer side of the nerve; which are the lachrymal and central retinal branches.

2nd. Those given off while the artery is above the optic nerve ; which are the posterior ciliary branches, the long ciliary or arteries of the iris, the muscular, and the supra-orbital.

3rd. Those given off on the inner side of the optic nerve ; being the æthmoidal, the palpebral, the nasal, and the frontal branches.

1st. *The lachrymal* is given off immediately the ophthalmic artery enters the orbit, indeed, sometimes before it has done so. It is one of the largest and most regular branches. It runs close to the external wall of the orbit, upon the upper edge of the adductor muscle, to which it gives branches, as far as the upper surface of the lachrymal gland, where it divides into several branches which enter the substance of the gland, for the secretion of tears, many being continued into the eye-lids and conjunctiva, where they assist in forming that free anastamosis which is here found. In this course the lachrymal artery sends twigs to the neighbouring parts in the orbit, inosculates, through the sphenoidal fissure with the middle meningeal artery, and through the malar foramina with the temporal and transverse facial arteries.

2nd. The *central artery of the retina* is a minute vessel, it penetrates into the centre of the optic nerve, in which it runs into the globe of the eye, passing through the cribriform plate of the sclerotic coat by the central aperture, which is called the *porus opticus*, where it appears as a dark spot upon the nerve, and immediately divides into two or three principal branches whose course will be traced when the retina is described.

3rd. *The posterior ciliary arteries* are a varying number of delicate tortuous branches, from eight to twelve or more, they are not always all given off from the ophthalmic trunk, but often part of them arise from one or more of its branches. They twine round the optic nerve, upon which they inosculate with each other and subdivide into a greater number of twigs; having reached the sclerotic coat they pass through it, with the ciliary nerves, by minute oblique openings, about the one-eighth of an inch from the optic nerve; passing forwards, they gain the inner surface of the choroid coat, which, by the meshes they form, is in a great degree made up. As they gain the anterior parts of the choroid their course is more directly towards the ciliary body and processes, to which they send a vast number of branches, as will be hereafter more particularly shown.

4th. *The long ciliary arteries* are two in number. They commonly are given off by the ophthalmic trunk and are perhaps of all the arteries in the orbit the most regular in their course and distribution, indeed, though small, they are important. Their course is tortuous, until having gained the globe, they pierce the sclerotic coat, somewhat anterior to the mass of posterior, or short ciliary arteries, and run exactly parallel to each other in the horizontal diameter of the eye, in a slight groove in the sclerotic coat, between it and the choroid, to the ciliary circle, which they pass through, to gain the outer or larger margin of the iris, where each divides into an upper and lower branch, which course round this margin to meet those from the opposite side, and thus form a vascular ring. Their ultimate distribution belongs to the structure of the iris. In their course each branch is accompanied by a nerve whose ultimate distribution closely resembles that of the arterial branches. They give very few twigs to the choroid or sclerotic coats, and their position is generally to be seen in the unopened eye, by the dark line of their course along the sclerotic coat. Though called the long ciliary arteries, following the usual mode of nomenclature adopted in other parts of the body, they should rather be called the arteries of the iris, to which they are almost exclusively distributed.

5th. *The muscular arteries* are sometimes described as a superior and inferior branch, but they are very irregular in origin and number; they supply the adipose and cellular tissues, and the various muscles within the orbit, following, to some extent, the division of the third pair of nerves so far as its twigs run, and with them passing into the ocular surfaces of the muscles; many twigs from them pass upon the tendinous expansion of the four straight muscles, forming a most delicate and complex web of vessels upon the forepart of the sclerotic coat, which, about one-tenth of an inch behind the cornea, they penetrate, to assist in supplying the iris and ciliary processes. These vessels form the red zone indicative of deep-seated inflammation of the eye, and it is when such a condition exists that by looking at them with a magnifying glass we obtain a better conception of their number and minuteness than by post-mortem injection, as in a state of health they are so small as not to carry red blood nor readily admit the materials used in injections. These small branches are called the *anterior ciliary arteries.*

6th. *The supra-orbital artery* is commonly the largest branch of the ophthalmic. It runs in company with the frontal nerve, above the levator palpebræ superioris muscle, immediately under the periosteum, to the superciliary notch, round which it turns, appearing, not uncommonly, at this point, larger than at its origin, to ramify and mount upon the skin of the forehead into the scalp, which it assists in supplying with blood, inosculating with the nasal and temporal arteries. In this course it supplies the muscles at the upper part of the orbit with blood.

7th. *The æthmoidal arteries* are two in number, of which the posterior is the larger, and when only one is present, it is that; it passes through the posterior æthmoidal foramen, crosses the cribriform lamella of the æthmoidal bone, and passes into the nose. It supplies the posterior æthmoidal cells, and also freely inosculates upon the Schneiderian membrane with the nasal twigs of the internal maxillary artery. The anterior æthmoidal artery, when present, is less than the posterior; it passes with the nasal nerve through the anterior æthmoidal foramen, supplying the anterior æthmoidal cells, and anastamoses with the branches of the last vessel upon the mucous lining of the nose.

8th and 9th. *The palpebral branches* are the superior and inferior, for supplying the upper and lower lids. They often arise by a common trunk immediately below the pully of the oblique muscle; twigs are sent to the lachrymal sac, to the caruncula, and the semilunar fold of the conjunctiva. The artery, supposing there be a common trunk, then divides into two branches, which run within the structures of the upper and lower lids respectively, supplying the tissue of the lids freely with blood, and forming as seen in fig. 68 very numerous anastamoses with all the neighbouring arteries.

10th and 11th. The ophthalmic artery having now reached

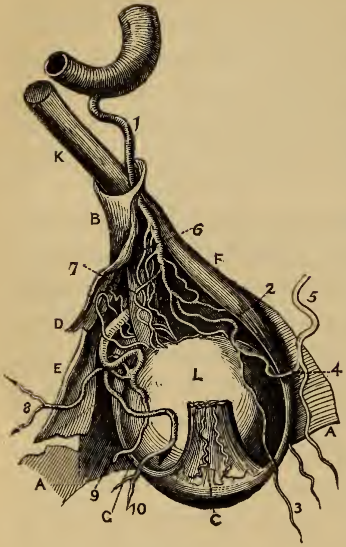

Fig. 78.

the inner angle of the eye, divides into its two terminal branches — the *frontal* and the *nasal.* The first passes out of the orbit between the pulley of the superior oblique and the tendon of the orbicularis muscles, it then turns upwards by the side of the internal angular process of the frontal bone, and dividing into branches supplies the root of the nose and the inner parts of the brow,—forming junctions with the branches of the supra-orbital artery, and with the frontal of the opposite side. The nasal branch escapes from the orbit with the last, but turns downwards, towards the side of the nose, where it communicates by a large trunk with the angular branch of the facial artery, forming a very free communication between the vessels, and also smaller anastamoses with other arterial twigs in this situation, and gives many branches to the lachrymal sac and inferior lid, &c.

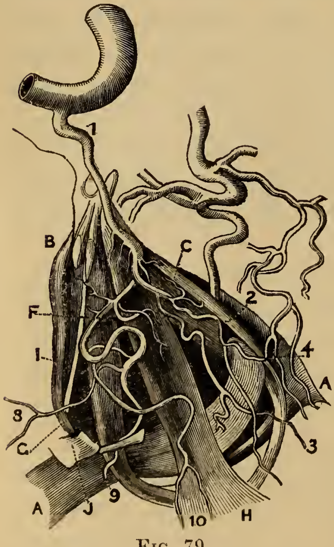

Fig. 79.

The branches of the ophthalmic arteries are very tortuous, and from the numerous junctions they form with other vessels, must contain a supply of blood whose momentum must be equable, though modified, and the impetus probably lessened by the opposing direction of the force in the different vessels, so that a constant

Figs. 78 and 79 show as plainly as the nature of the parts will allow the course and distribution of the ophthalmic artery in the left eye of the adult.

stream of nearly uniform pressure will be always sent through the interior of the eye-ball, which is not likely to be interrupted by the various motions of the part, or the different positions of the body; the tortuous direction of the vessels guarding against the one, and the numerous anastomoses against the other, as well as against the danger of obstruction in any one channel of supply.

VEINS OF THE ORBIT. As the blood which has circulated within the cranium by the internal carotid artery is not returned by veins which correspond with its branches, as is the rule in other parts of the body, so the blood which has been conveyed by the ophthalmic artery, a branch of the internal carotid, is not all returned by corresponding veins; for much of the blood which has been distributed by those branches which have passed out of the orbit is collected by veins which pass to the frontal, temporal, and facial, and thus finds its way back to the heart, by the external jugular and connecting branch of the internal jugular veins. That portion of blood, however, which has circulated within the ball of the eye, and within the cavity of the orbit, is collected by numerous branches, which though irregular in number and course, all ultimately unite into one short trunk, the *ophthalmic vein.* Fig. 80. This, which is much larger in size than the artery of the same name, lies below, and to the outer side of the optic nerve, separated from it by the lenticular ganglion and, proceeding backwards, it passes out of the orbit into the skull by the sphenoidal fissure, as the nerves enter it, entering by the side of the sella turcica the cavernous sinus,

In fig. 78, the globe of the eye is in situ with the levator of the upper lid divided and turned back, the superior oblique altogether removed. In fig. 79, the two former muscles are altogether removed, as is the eye-ball, but the superior oblique muscle is left in situ, the same letters refer to the same parts in both figures; A A the margin of the orbits. B the passage of the optic nerve and ophthalmic artery through the foramen opticum. C the anterior portion of the superior rectus muscle. D the posterior part turned back. E the levator palpebræ turned back. F the outer straight muscle. G the inner, and H, the inferior straight muscle. I the superior oblique muscle passing through its pulley J. K the optic nerve. L the ball of the eye. 1, the ophthalmic trunks; 2, the lachrymal artery, which after giving off muscular branches, and in this instance ciliary arteries, divides into the proper lachrymal 3, and 4, an inosculating branch to join with 5, one from the internal maxillary artery, 6 ciliary arteries, 7 muscular branches, 8 ethmoidal arteries, 9 the nasal, and 10 the frontal arteries.

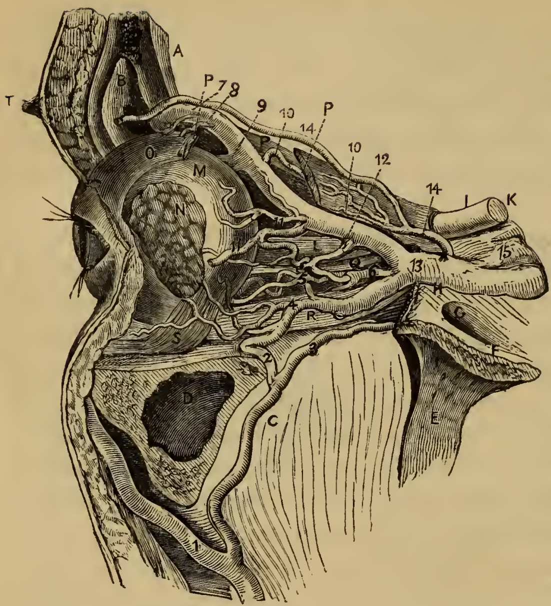

Fig. 80.

and thus the vein may be said to constitute the commencement of this sinus.

Nerves of the orbit. In no space of like size in any other part of the body is there to be found such a number of nerves as are distributed within the orbit; moreover, not merely are they remarkable in this respect, but also for the different properties they possess and the number and variety of their connexions. Thus there is the second pair or optic nerve,—one of special sensation; the first division of the fifth pair of nerves,—a nerve of ordinary sensation; the third pair, conferring motor power upon five out of the seven muscles within the orbit; the fourth and the sixth pairs, both nerves of motion; but, inasmuch as they present the remarkable singu-

Fig. 80. Left orbit laid open and dissected from the external side to show the ophthalmic vein and its branches. a, frontal bone; b, frontal sinus; c, maxillary bone; d, antrum; e, pterygoid process; f, ala majora of the sphenoid bone; g, foramen rotundum; h, superior orbital fissure; i, optic nerve; k, its cerebal portion; l, the orbital part; m, the eye-ball; n, lachrymal gland; o, levator muscle of upper eye-lid; p, superior rectus, the middle portion of those two muscles being cut away to show the course of the vein; q, internal rectus; r, inferior rectus; s, inferior oblique muscle. T, Eye-brow

1, facial vein; 2, *anterior or facial ophthalmic vein*, which joins with 3, speno-palatine vein and receives 4, inferior muscular branches; 5, external posterior ciliary branches; and 6, the zygomatic branch; 7, *posterior or cerebral ophthalmic vein* which receives 8, palpebral vein; 9, vorticose vein from choroid; 10, superior muscular; 11, lachrymal; and 12, external muscular veins; 13, communicating branch with anterior ophthalmic; 14, supra-orbital vein; 15, cavernous sinus.

larity (for no other nerves in the body are so circumstanced) of each passing to an individual muscle, to which it is almost—some anatomists say quite—exclusively distributed, we must conclude they possess some special property, which other motor nerves do not; otherwise we cannot conceive why the superior oblique and abductor muscles should not be supplied from the third pair as the other five orbital muscles are: the place of connexion of these nerves with the central nervous mass, and the fact of the muscles not receiving any other motor nerves, prove them to be motor trunks, but what other faculty they enjoy is not known; hypotheses are not wanting, but as yet they are mere speculations. Lastly there is the lenticular ganglion, receiving from, or giving branches to, the third and fifth pairs, by which it is brought into connexion with the other portions of the ganglionic system, and supplying the greater part of the nervous filaments of the eye-ball.

The optic nerve, large, round, and encased in a dense firm neurilemma connected with the dura mater, after having upon the processus olivarium of the sphenoid bone united with its fellow in the commissure,* passes out of the cranium by the foramen opticum, in a diverging manner, to enter the eye-ball through the cribriform portion of the sclerotic coat to the inner and under side of the optical axis. In this course it is surrounded by the four straight muscles, but separated from them by the soft adipose matter before mentioned, and by various vessels and nerves. It is somewhat curved, being longer than the space which it traverses, so that in the various motions of the globe no tension is ever experienced by it.† Its course and connexions within the cranium and eye are points of extreme interest to be discussed hereafter.

The third, fourth, fifth, and sixth nerves enter the orbit by the sphenoidal fissure, after passing through the cavernous sinus, between its two coats, in which they lie to the outer side of the carotid artery. If we take the middle of the sinus, we find, most superiorly, the third, then the fourth, next the ophthalmic division of the fifth, and below, all close to the artery, and to the inner side of the fifth pair is the sixth nerve. In the sinus is a plexus of small nerves, described as filaments from the superior cervical ganglion of the sympatheticus, with these filaments are connected the orbital nerves, particularly the fifth and sixth, but Dalrymple says he has seen these sympathetic twigs connected with almost every nerve contained in the sinus; a statement with which most recent anatomists will agree. Just before entering the orbit the relation of these nerves to each other is not the same as in the middle of the sinus; the third has divided into its two branches, and the fifth into its three; most superiorly is the fourth nerve, then the frontal branch of the fifth, the upper or small branch of the third follows, then the lachrymal, next the nasal, below which is the second or larger division of the third, and beneath all is the sixth nerve. Of these the fourth and frontal branch of the fifth enter the orbit above the abductor muscle, the others between its two heads and above the ophthalmic vein.

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* For the course of the optic trunk and its connexions with the cerebral mass, see Physiology of Vision,—*single vision with two eyes.*

† The length of the optic nerve in different animals differs much, but in all it is greater than the mere distance it has to traverse, depending upon the extent of space between the eye-ball and the brain, and the fixidity or mobility of the ball, care being always taken that no stress shall be put upon the nerve. In the bottle-nosed whale the optic nerve is near 15 inches long. In the common snail—*Helix hortensis*, the black slug, *Limulus ater*, and many other tentaculated moluscæ, the nerve when the tentaculum is retracted is very much convoluted to allow of the protrusion of it.

The *third pair of nerves*, the common motor nerve of the eyeball, is a firm round cord, and is connected with the part in the cerebrum corresponding with the anterior cords of the spinal column, appearing at the edge of each crus cerebri, anterior to the pons varolii, and posterior to the corpora albicantia; but some of the fibres may be traced into the locus niger of the crura, and others into the corpora quadrigemina; while Stilling and Kolliker say the major part arise from the floor of the aqueduct of Sylvius. After receiving a filament from the sympathetic in the cavernous sinus, it divides into an upper smaller, and a lower larger branch; both enter the orbit between the two heads of the abductor muscle.

The smaller branch proceeds forwards and upwards, above the optic and nasal nerves; where it divides into twigs which run into the ocular surface of the superior straight and the levator palpebræ muscles. The twigs anastomose with those of the nasal nerve. The larger branch passes downwards and forwards, beneath the optic nerve, between this and the inferior straight muscle, where it divides into three branches,—one of which after ramifying immediately passes into the depressor muscle; an internal branch, which is distributed to the adductor muscle; and a third branch, which is the longest and largest; it passes between the inferior and external recti muscles, but without furnishing any twig to either, to be distributed to the inferior oblique muscle, having first sent to or received from the lenticular ganglion, a short thick communication; all the branches of the third pair of nerves enter the ocular surface of the muscles.

The fourth pair of nerves, nervus trochlearis, nervus patheticus, is the smallest of all the cranial nerves, and has usually been described as exclusively distributed to the superior oblique muscle, which is not altogether correct; for Mr. Swan describes the nerve going to the lachrymal gland as partly made up of a branch from the fourth, which joins the proper lachrymal nerve of the fifth pair, an anastamosis which Mr. Dalrymple says he also has seen, as well as junctions between it and the sympathetic filaments in the cavernous sinus; though these anastomoses probably are rather to be regarded as the exception, than the rule, as Mr. Swan seems inclined to think. The fourth nerves are connected with the central nerve mass by two small bundles of fibres from the valve of Vieussens, and the floor of the fourth ventricle; after a long course (the longest of any of the cranial nerves) it enters the cavernous sinus, at first below the third pair, but near the orbital fissure it mounts above this nerve, and, in company with the frontal nerve, enters the orbit above all the muscles, and passes obliquely, immediately under the periosteum, to the superior oblique muscle, before entering which, being first somewhat increased in size, it divides into four or five twigs, which enter the upper surface of the muscle.

The *ophthalmic division of the fifth pair of nerves* (*trigeminal, trifacial*) is exclusively derived from the posterior portion of the fibres of the nerve, whose central connexion is with the lateral part of the medulla oblongata, continuous with the floor of the fourth ventricle; it is therefore a nerve of sensation. It is the first and smallest of the three portions which proceed from the Casserian ganglion; it immediately enters the cavernous sinus, where it receives twigs from the sympathetic plexus, and at first lies below the fourth and above the sixth nerves, but before entering the orbit it has divided into three branches, the frontal or supra-orbital, the lachrymal, and the nasal nerves.

The *frontal* is the largest of the three branches; it enters the orbit in company with the fourth nerve, above the muscles, running forwards upon the levator palpebræ, under the periosteum towards the base of the orbit, about midway between which and the apex, the nerve divides into an outer larger branch, the proper supra-orbital, and an inner smaller, the supra-trochlear. This latter branch passes out of the orbit above the pulley of the inferior oblique muscle, where it immediately divides and subdivides into numerous branches for the supply of the muscles and integuments here situated (fig. 67). The supra-orbital escapes at the notch or foramen of the same name to give sensation by its ramifications to the parts about the brows and forehead, some of the branches running a long way in the pericranium. No branches have been noticed as given off by the frontal nerve to the parts within the orbit.

The *nasal nerve* enters the orbit between the two heads of the abductor muscle, in company with, but lying above the third and sixth nerves—it runs obliquely inwards and forwards to the inner side of the orbit, above the optic nerve and beneath the superior rectus muscle, where it divides into two branches,—the proper nasal and the infra-trochlear. In this course it gives off directly on entering the orbit, while between the two heads of the muscle, and outside the optic nerve, a slender branch, about an inch in length to the upper angle of the posterior edge of the lenticular ganglion, which filament is asserted by some anatomists to be the identical twig it received, while within the cavernous sinus, from the sympathetic plexus; as it passes over the optic nerve the nasal gives off two or three filaments,—the long ciliary nerves, which enter the back part of the sclerotic coat, with the other ciliary nerves, and run between it and the choroid as far as the iris. The *infra trochlear* branch runs forwards, beneath the pulley of the superior oblique muscle, where it divides into numerous filaments to anastomose with nervous twigs, from the supra-trochlear, facial, and supra-orbital nerves supplying the lachrymal sac, conjunctiva, eye-lids and neighbouring integuments with sensation (fig. 67). The internal or proper nasal nerve enters the cranium by the anterior æthmoidal foramen, crosses the cribriform plate, and descends by the side of the crista galli into the nasal fossa, where it divides into anterior and posterior filaments, for the supply of the Schneiderian membrane, and the skin of the nose.

The *lachrymal nerve* is the smallest of the three branches of the ophthalmic portion of the fifth; it enters the orbit with the last, runs along the upper edge of the abductor muscle, with the lachrymal artery, to the lachrymal gland; it sends off a branch through the spheno-maxillary fissure to communicate with the inferior maxillary nerve and another branch through the malar bone, to join the facial nerve. Near the gland the nerve divides into two or more filaments, which soon again subdivide, and penetrate the substance of the gland, many of the filaments being ultimately lost in the conjunctiva and eyelids, where they unite freely with the facial twigs. This nerve is sometimes formed, as figured by Swan, of a branch from the fourth nerve and the lachrymal branch of the fifth.

The *sixth pair* or *abducens nerve* is intermediate in size between the third and fourth pairs. Its internal attachment is to the pyramidal body of the medulla oblongata, close to the pons Varolii; it lies below all the other nerves, in the cavernous sinus close to the carotid artery and is less attached to the fibrous walls of the sinus than the other nerves; receiving one or two twigs from the sympathetic plexus, it enters the orbit below the third pair of nerves and above the ophthalmic vein; it is usually distributed by two or three filaments to the ocular surface of the abductor muscle exclusively, sometimes, however, it is connected with the nasal nerve and the lenticular ganglion by minute twigs.

The *lenticular ganglion* is a minute mass belonging to the ganglionic system, situated at the back part of the orbit, to the outer side of the optic nerve and the inner side of the abductor muscle, between the ophthalmic artery and vein, and in the angle formed by the common motor and nasal nerves. It is embedded in fat, and, from its shape, colour, and size, is not unlikely to be cut away with the fat globules. It is somewhat quadrangular, of a pale reddish colour; by its superior posterior

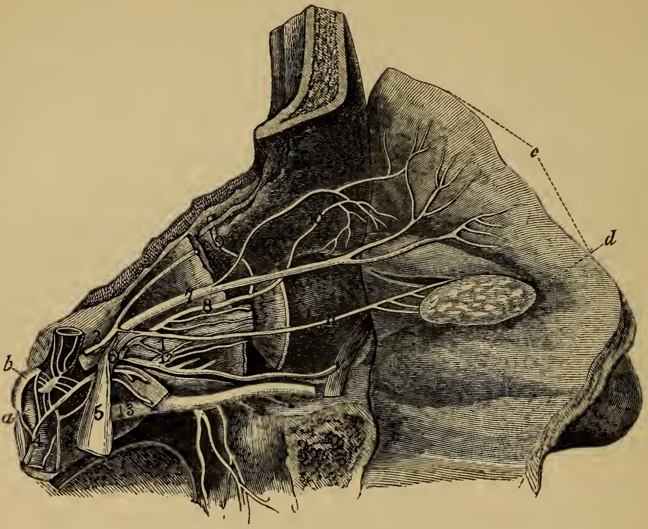

Fig. 81.

angle, it receives the branch from the nasal nerve, by its inferior posterior angle the branch from the inferior oblique fasciculus of the third nerve, (motor oculi) while from its anterior part proceed the short ciliary nerves,—about five or six from its upper angle and ten or twelve from its lower: these all twine round the optic nerve, accompanied by the long ciliary filaments from the nasal, and with the ciliary arteries in a tortuous manner anastamosing with each other; they pierce the sclerotic coat, about two lines from the entrance of the optic nerve, by numerous oblique foramina, and run forwards be-

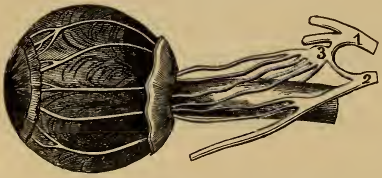

Fig. 82.

Figs. 81 and 82 will show the general arrangement of the nerves of the orbit.

Fig. 81. *a*, internal carotid artery; *b*, cavernous plexus; *c*, skin of forehead; *d*, lachrymal gland. 1, optic nerve; 2, third nerve; 3, fourth nerve; 4, sixth nerve; 5, part of Gasserian ganglion; 6, first trunk of fifth nerve; 7, supra-orbital branch of fifth; 8, nasal branch, dividing into 9, proper tween the choroid and sclerotic coats in grooves in the latter, as far as the ciliary circle and iris, where they will afterwards be traced.

THE GLOBE OF THE EYE.

It has already been stated that the orbits are much larger than the eye-balls, and that their axes do not correspond, but diverge considerably in an outward direction, while those of the two eyes are perfectly parallel. The eye-balls lie in the fore-part of the orbits, and according as they are more or less prominent, and more or less covered with the lids, do they appear to be larger or smaller. The eye-balls themselves undoubtedly do differ somewhat in size in different persons, but the apparent difference is often greater than the real, depending, as some have asserted, entirely upon the size of the opening of the lids; though I feel certain the actual difference in size is greater than has been suspected, as the following table of measurements will prove.

In infants and young children, in proportion to the size of the body, the eye is larger than it is in the adult, and the eye of a man is commonly said to be larger than that of a woman; as a naked fact in the majority of cases this is undoubtedly correct, as men are larger than women, but I very much doubt if regard be had to the different sizes of the male and female bodies it is true. I incline to think that if two eyes taken the one from a man, the other from a woman, whose bodies are precisely of the same size and strength of development, are accurately measured, they will be found to be of the same size, at least I have measured female eyes as large as the average of male eyes, and one taken from a large woman was the largest eye but one I ever measured.

The human eye-ball is described by some anatomists as being a true sphere, but by the greater number, as being a spheroid,

nasal; and 10, the infra-trochlear nerve; 11, the lachrymal; 12, lenticular ganglion and nerves; 13, superior maxillary nerve.

Fig. 82 shows the branches forming the lenticular ganglion and the ciliary nerves from it:—1, third nerve; 2, nasal nerve, sending branches to ganglion and also the long ciliary nerves; 3, lenticular ganglion, sending off ciliary nerves, which are seen upon the choroid coat, the sclerotic having been cut away anterior to the entrance of the nerves through it.

the diameter of which, from before to behind, is somewhat greater than in any other direction. The supposed difference being stated to arise from the anterior sixth of the sclerotic coat being truncated, as it were, and the deficiency supplied by the insertion of the cornea, which, being a segment of a smaller sphere than the sclerotic, consequently is thought to project beyond the convexity of the larger sphere. By some the antero-posterior diameter is given at 11 lines, the transverse diameter at only 10. Petit described the proportion of the antero-posterior to the transverse diameter as 136 to 135; Soemmerring as 10 to 9·5.

It is not improbable that while the posterior part of the human sclerotic coat is under all circumstances a portion of a perfect sphere, that the anterior part of it and the convexity of the cornea vary to some extent in different subjects, and even in the same individual at different times; but I am much inclined to think whatever departure there is from a spherical figure is in the contrary direction to that which it has been so confidently and commonly stated to be, and that the opinion of the antero-posterior diameter being larger than the transverse has rather been formed from looking at a section, where the projection of the smaller curve of the cornea, set in as it is, to the somewhat flattened termination of the sclerotic, gives rise to the appearance of greater projection than to actual measurement of the two diameters. It would be difficult to give any optical reason why the antero-posterior diameter should be the largest, and analogy is decidedly against the supposition, for in all animals where there is any decided difference in the two diameters, the transverse is the greatest; in many instances the difference being very considerable. Thus in the ox the antero-posterior diameter is to the transverse as 43 to 49, in the sheep as 32 to 35, in the horse as 28 to 31, in the pig as 27 to 32, in the hare as 23 to 25, in the squirrel as 11 to 12, in the mysticete whale as 20 to 29, in the turkey as 23 to 31, in the Guinea fowl as 16 to 20, in the grouse 14 to 20, in the partridge as 12 to 17, in the common fowl as 17 to 23, in the rook as 17 to 22, in the swan as 19 to 26, in the duck as 17 to 20, in the goose as 20 to 25, in the alligator as 26 to 29, in the green turtle as 25 to 37, in the common toad as 18 to

19, in the common frog as 32 to 35, in the toad as 34 to 38, in the basking shark, as 7 to 12, in the salmon as 15 to 23, in the salmon trout as 11 to 18, in the trout as 7 to 13, in the greyling as 9 to 13, in the dace as 7 to 11, in the golden carp as 6 to 7, in the eel as 13 to 17, in the cod as 29 to 42, in the haddock as 28 to 40, in the whiting as 12 to 18, in the mackerel as 14 to 20, in the herring as 11 to 18, in the viper fish as 6 to 8, in the halibut as 25 to 34, in the sole as 10 to 13, in the sand-dab as 8 to 12.

As, however, this opinion is opposed to the statement so generally made, I have taken considerable pains in accurately measuring a great number of eyes of both men and women and of various animals; the latter almost immediately after death, most of them instantly the animal was killed. The human eye is very difficult to be obtained shortly after death, and it so soon becomes flaccid as to render care necessary, lest this should deceive ; but as in some instances it was obtained within four or six hours of death, in one within a few minutes after removal by operation for cancer of the lids adhering to the *conjunctiva oculi*, and in other cases when there was any flaccidity the rotundity was restored by inflation of air through the optic nerve, I have little doubt of the correctness of the measurements. In some instances the difference between the two diameters was scarcely perceptible, in all where a distinction was observed the transverse was the greatest. In all cases I have given the circumference as more likely to be free from fallacy than the diameter alone, the eye being unopened and in a natural state of tensity, and in most instances the diameters are also given.

The subjoined tables of measurement are also of importance as showing the form and size of the cornea and particularly in pointing out the situation in which the optic nerve enters the sclerotic, and its distance from the axis of the eye. That in man and a great number of animals it does so to the inner side of the axis all anatomists have for long pointed out, but so far as I am aware it has never been observed that not only is the entrance eccentric as regards the axis transversely, but it is also eccentric vertically, in almost as great a degree in man, and in many animals to a much greater extent. The distance from the entrance of the optic nerve over the upper surface of the sclerotic to the top margin of the cornea being in man decidedly greater than it is along the under surface to the lower margin, while in some animals the contrary prevails. How this should have escaped observation it is difficult to say, perhaps there being no such apparent reason why it should be so, and the less extent of the difference in man, may be the explanation. The inner eccentricity of entrance has been regarded as an anatomical convenience and a physiological necessity. The divergence of the optic nerves rendering this position convenient, and the insensibility of the nerve as it appears in the eye making it imperative that it should not be placed in the visual axis, where images would be constantly thrown upon it. There however not improbably is contained in this oblique entrance of the optic nerve an explanation, or at any rate a connexion, with a physiological problem of high interest, to which hereafter I shall have to refer more at length, contenting myself here with a mere allusion to it, and pointing out the fact that the degree of this departure from centricity differs most remarkably in different animals, and that the obliquity or parallelism of the axes of the two eyes also differs in different creatures, as consequently must the relative position of two images from a single object, according as the eyes are placed laterally or anteriorly in the head. That there is such general agreement the tables I think sufficiently show, but that there is such constant and unvarying agreement between the two as to connect them essentially together as cause and effect I am not prepared unhesitatingly to assert—that would require an immense number of careful observations and will be discussed in its proper place, when we come to the physiology of vision. The subject would not have been here mentioned, except as the measurements of the exterior of the eye are here placed it is necessary to explain why they are so dwelt upon and to save a repetition hereafter. For this reason I shall not only give the measurement of several human eyes, but also of many animals. It will be observed that in every case the distance of the optic nerve from the upper and lower edges of the cornea is not given, at the time they were made I had not observed the constancy of the difference—but instances where it is given are so numerous as to show it to be the rule. That in every instance the measurements are absolutely and mathematically correct I will not assert—the yielding flaccidity of the eye-ball rendering this almost impossible:—that they are substantially so, I have taken every pains to ensure. I should mention that the distance is taken in a straight line from the middle of the optic nerve to the edge of the cornea; so that where this enters considerably above or below the axis of the globe as in the horse, ox or sheep for instance, the transverse distance is not that over the middle of the sclerotic coat, but of a line below this, corresponding with the entrance of the optic nerve. This must be borne in mind in case any one should take the trouble to verify these measurements. So also in all probability where the ball has been distended with air, though the sclerotic and cornea are not elastic, still something must be allowed in the measure for greater tension than in the living eye-ball, as undoubtedly the inflated eye-ball measures something more than the uninflated.

The measurements are given in inches and thirtieths of an inch, except in a few of the smaller eyes, where the sixtieth of an inch is used, and in all cases, slighter differences are not noticed, as for instance when its measurement is between two-thirtieths, the one nearest was set down, this being sufficient for all purposes of comparison. The cornea is measured over its curve.

THREE EYES FROM TWO ADULT MEN.—No. 1, age and cause of death unknown. No. 2, æt. 60, died of phthisis, both eyes alike in all respects.

	Inch.	
	No. 1.	No. 2.
Antero-posterior vertical and horizontal circumference alike, eye quite globular	3·0	3·0
Distance from centre of optic nerve to outer margin of cornea	1·11	1·9
Do. to inner margin	1·1	1·2
Cornea circular in each direction	·11	·13

FOUR EYES FROM THREE WOMEN.—No. 3, both eyes measured alike, æt. 34, died of phthisis. No. 4, died of carcinoma, æt. 54. No. 5, æt. 60, measured immediately after eye had been removed by operation for carcinoma of lids, with adhesion to sclerotic conjunctiva, but not otherwise affecting the ball; the sight was quite perfect. It is the largest eye, with one exception, I ever measured; so far as could be ascertained, the other eye was of equal size.

		Both Eyes.	
	No. 3.	No. 4.	No. 5,
Antero-posterior circumference vertical	3·0	2·26	3·3
Horizontal do.	3·0	3·28	3·4
Transverse do.	1·1	3·0	3·6
From centre of optic nerve to outer margin of cornea	1·9	1·9	1·12
Do. to inner margin	1·0	1·1	1.3
Transverse diameter of cornea	·18	·16	·18
Vertical do.	·16	·15	·15

Four Eyes taken from two Women.—No. 6, died from serous apoplexy, æt. 70 years. The measure of both eyes was alike in all respects, except that the vertical diameter of the left eye was $\frac{1}{30}$ less than that of the right. Arcus senilis large and complete in both. No. 7, died from disease of heart and albuminuria, æt. 40 years.

	No. 6.	No. 7.	
	Both.	Right.	Left.
Antero-posterior circumference, vertical	2·26	2·25	2·26
Do. do. horizontal	2·28	2·26	2·26
Transverse circumference	2·29	2·27	2·27
Antero-posterior diameter	·28	·28	·28
Vertical do.	·29	·28	·28
Horizontal do.	·29	·28	·28
From centre of optic nerve to outer margin of cornea	1·10	1·9	1·10
Do. to inner margin	1·2	1·1	1·0
Do. to upper margin	1·6	1·5	1·5
Do. to lower margin	1·4	1·4	1·5
Transverse diameter of cornea	·16	·17	·17
Vertical do.	·15	·16	·16
Length of cord of cornea	·14	·13	·14
Depth of curve of do.	·4	·4	·5

Four Eyes from two adult Male Subjects, measured within a few hours after death; both the eyes in each measured exactly alike.

	No. 8.	No. 9.
Antero-posterior circumference, vertical	3·0	3·2
Do do. horizontal	3·0	3·2
Transverse circumference	3·2	3·3
Diameter, antero-posterior	1·0	1·1
Do. vertical	1·0	1·1
Do. horizontal	1·1	1·1
From centre of optic nerve to outer margin of cornea	1·9	1·11
Do. to inner margin	1·4	1·4
Do. to upper margin	1·9	1·11
Do. to lower margin	1·7	1·6
Horizontal diameter of cornea	·18	·14
Vertical do.	·17	.13

Six Eyes taken from three adult Males, measured soon after death; the eyes in each exactly corresponded.

	No. 10.	No. 11.	No. 12.
Antero-posterior circumference, vertical	2·25	2·29	2·29
Do. do. horizontal	2·26	2·29	2·29
Transverse circumference	2·27	3·1	2·29
Diameter, antero-posterior	·28	·29	·29
Do. vertical	·28	·29	·29
Do. horizontal	·28	1·0	·29
From centre of optic nerve to outer margin of cornea	1·8	1·12	1·11
Do. to inner margin	·29	1·1	1·2
Do. to upper margin	1·6	1·9	1·8
Do. to lower margin	1·4	1·5	1·6
Horizontal diameter of cornea	·16	·17	·16
Vertical do.	·15	·15	·15
Length of cord of segment of cornea	·14	—	·14
Depth of curve of do.	·4	—	·3

Four Eyes from two Male Subjects.—No. 13, average-size man, æt. 52, who died from tumour in the left hemisphere of cerebrum; the sight had been good until he was just moribund; measured thirty-two hours after death. The right eye was plump and natural, but the left had been compressed in removing from the orbit, and was therefore distended with air. This will account (and probably indicate the amount of distention that may thus be caused) for the difference in the two eyes, as regards the mere size, but it will not for the difference in the position of the optic nerve as it enters the eye, which must therefore be taken as showing that a difference in this respect really does at times exist in the two eyes, without affecting the functions, so far as can be ascertained. No. 14, also average-size male, a vagrant; died from some affection of chest.

	No. 13.		No. 14.	
	Right.	Left.	Right.	Left.
Circumference, antero-posterior vertical	3·2	3·4	3·0	3·0
Do. horizontal	3·3	3·4	3·1	3·1
Do. transverse	3·3	3·4	3·1	3·1
Diameter, antero-posterior and vertical, alike	1·0	1·1	1·0	1·0
Do. horizontal	1·1	1·1	1·0	1·0
From centre of optic nerve to outer margin of cornea	1·12	1·11	1·11	1·12
Do. to inner margin	1·5	1·7	1·6	1·5
Do. to upper margin	1·9	1·9	1·7	1·8
Do. to lower margin	1·7	1·7	1·7	1·8
Do. along outer side to centre of cornea	1·20	1·21	1·19	1·20
Do. along inner side to do.	1·13	1·14	1·14	1·13
Do. along upper side to do.	1·17	1·18	1·15	1·16
Do. along lower side to do.	1·15	1·16	1·15	1·16
Transverse diameter of cornea	·16	·17	·16	·16
Vertical do.	·16	·17	·15	·15
Length of cord of cornea	·15	·15	·14	·14
Depth of curve of cornea	·4	·4	·4	·4

Two Eyes from Male Subject.—In the following table, the measurements are those of the eyes of a full average-size man, about fifty years old, who died of malignant disease of the liver. The eyes are the largest I ever measured, though something must be allowed from the figures, for the balls being distended with air, and consequently rendered somewhat more tense than natural; but still, with every deduction, the figures show, in comparison with most of the others, that a considerable difference in the size of the eye-balls really does occur; the optic nerves were the largest I ever saw—twice the normal size. During life nothing unusual had been noticed about the eyes. Vision was good and the enlarged size did not result from malignant infiltration. Except the two cornea not being of precisely the same size in all other directions, the dimensions were alike.

	No. 15.
Circumference, antero-posterior vertical and horizontal, alike	3·7
Do. transverse	3·11
Diameter, antero-posterior	1·2
Do. vertical and horizontal	1·3
From centre of optic nerve to outer margin of cornea	1·13
Do. to inner margin	1·7
Do. to upper margin	1·13
Do. to lower margin	1·10
Transverse diameter of cornea	·17
Vertical do. (left eye ·16) right eye	·15
Segment of cornea	·14
Depth of curve of do.	·4
Circumference of optic nerve, including sheath, at half-an-inch from the eye-ball	·24
Do. without sheath	·15

TWO EYES FROM MALE.—The position of the optic nerve, at its entrance into the sclerotic coat, in the man of whose eyes the next table contains the measurements, differs so much from what I have found in any other person, that had I not removed the eyes from the orbit myself, I should have concluded some error had occurred, but this I think impossible, for at first only the right eye was removed; when finding the position of the nerve so unusual, I removed the left with the greatest caution. I went over the measurements repeatedly, with all the care I am capable of, always with the same result, of making the position of the nerve different from every other eye, and with the equally curious fact of making those of the two eyes differ very much from each other. The subject had been dead some little time before I could obtain the eyes, which being flaccid were distended with air, so that absolutely true dimensions may not have been obtained; yet as the eyes were equally distended, this would not affect the relative dimensions of them.

The man was about forty years old, of vagrant habits; he died of bronchitis. I have taken some trouble to trace him, while living, to ascertain if there had been noticed any peculiarity in his vision. I find that some months before his death he had been a patient in the infirmary, where his peculiar manner of holding a book or newspaper to one side, and very near to his face, had attracted the notice of other patients while there, and also of the master of the charity where he died. A companion also, when spoken to, mentioned it. Whether this obliquity of vision, which was probably myopic and mono-ocular, had any connexion with the unusual position of the optic nerve, I will leave others to speculate upon.

	No. 16.	
	Right.	Left.
Antero-posterior circumference, vertical	2·29	2·29
Do. horizontal	2·29	2·29
Transverse circumference	3·1	3·1
Antero-posterior diameter	·28	·28
Vertical do.	1·0	1·0
Transverse do.	1·0	1·0
From optic nerve to outer margin of cornea	1·6	1·8
Do. to inner margin	1·11	1·7
Do. to upper margin	1·8	1·9
Do. to lower margin	1.7	1·5
Transverse diameter of cornea	·15	·14
Vertical do.	·14	·15
Length of cord of cornea	·13	·13
Depth of curve of cornea	·4	·4

EIGHT EYES FROM FOUR HUMAN FŒTUS.—This child was a very bad case of spina bifida; but, in other respects, well and fully developed.

	No. 17.		No. 18.		No. 19.		No. 20.	
	Full Time.				5 Months.		15 Weeks.	
	Right.	Left.	Right.	Left.	Right.	Left.	Right.	Left.
Circumference, antero-posterior, vertical	2·7	2·8	2·3	2·4	1·24	1·24	1·11	1·11
Do. do. horizontal	2·6	2·7	2·4	2·4	1·24	1·24	1·10	1·10
Do. transverse	2·7	2·8	2·4	2·3	1·24	1·24	1·10	1·10
Diameter, antero-posterior	·22	·22	·22	·21	·18	·18	·13	·13
Do. vertical	·21	·22	·20	·19	·18	·18	·13	·13
Do. horizontal	·22	·22	·22	·21	·18	·18	·13	·13
From optic nerve to outer or posterior margin of cornea	·29	·29	·29	·29	·25	·25	·18	·19
Do. to inner or anterior margin	·24	·25	·22	·22	·19	·19	·14	·14
Do. to upper margin	·24	·25	·26	·26	·22	·22	·14	·14

	No. 17.		No. 18.		No. 19.		No. 20.	
	Full Time.				5 Months.		15 Weeks.	
	Right.	Left.	Right.	Left.	Right.	Left.	Right.	Left.
From optic nerve to lower margin	·26	·26	·24	·24	·21	·21	·16	·16
Diameter of cornea, transverse	·15	·14	·14	·14	·11	·12	·8	·8
Do. vertical	·14	·13	·13	·13	·10	·11	·7	·8
Length of cord of segment of cornea	·13	·13	·12	·12	·9	·9	·6	·7
Depth of curve of cornea	·3	·3	·4	·4	·2	·2	·1	·1

SMALL FEMALE ADULT APE.

	Inches.
Antero-posterior circumference	2.7
Transverse do.	2·6
From centre of optic nerve to outer margin of cornea	1·0
Do. to inner margin	·27
Cornea, circular diameter	·13

ADULT MONKEY (of moderate size.)

Antero-posterior circumference	2·4
Transverse do.	2·3
From centre of optic nerve to outer margin of cornea	·26
Do. to inner margin of cornea	·22
Do. to upper margin of cornea	·25
Do. to lower margin of cornea	·23
Transverse diameter of cornea	·14
Vertical do.	·12

In the other eye the cornea was less by $\frac{1}{30}$ of an inch in both directions.

SIX EYES TAKEN FROM THREE PIGS (of moderate size). The cornea of pig in form resembles an egg split longitudinally, the broader end being internal.

	No. 1.		No. 2.		No. 3.	
	Right.	Left.	Right.	Left.	Right.	Left.
Circumference, antero-posterior, vertical	2·28	2·27	2·25	2·24	2·24	2·24
Do. horizontal	3·0	2·29	2·26	2·25	2·25	2·25
Do. transverse	3·6	3·6	3·2	3·1	2·29	3·0
Diameter, antero-posterior	.27	·27	·26	·26	·25	·25
Do. vertical	·29	·29	·28	·28	·28	·28
Do. transverse	1·2	1·2	1·0	1·0	·29	1·0
From centre of optic nerve to outer or posterior margin of cornea	·29	·29	·29	·28	·27	·27
Do. to inner or anterior margin of cornea	1·5	1·5	1·5	1·5	1·3	1·2
Do. to upper margin of cornea	1·11	1·10	1·9	1·8	1·8	1·8
Do. to lower	·27	·28	·28	·28	·27	·26
Breadth of cornea	·24	·24	·23	·23	·24	·23
Depth of cornea in the centre	·20	·20	·19	·19	·19	·19
Do. near larger or inner curve	·21	·21	—	—	·20	·20
Do. near smaller or outer curve	·13	·13	—	—	·12	·12
Length of transverse cord of segment	·20	·20	·19	·19	·19	·19

	No. 1.		No. 2.		No. 3.	
	Right.	Left.	Right.	Left.	Right.	Left.
Depth of curve of cornea	7	·7	·6	·6	·6	·6
Length of vertical cord of segment of cornea	—	—	—	—	·15	·16

Four Eyes from two Dogs.—In each the two eyes measured alike. No. 1 was an old, rather large, King Charles' spaniel dog, in which the eyes were very prominent and set very obliquely in the head, as is common with the breed; No. 2 was a small Blenheim bitch, the eyes nearly parallel. Both were destroyed with hydrocyanic acid, which will perhaps account for the depth of curve of cornea, which is usually very prominent in death from this and analogous poisons.

	No. 1. Dog.	No. 2. Bitch.
Antero-posterior circumference, vertical	2·15	1·26
Do. horizontal	2·16	1·26
Transverse circumference	2·16	1·27
Antero-posterior diameter	·25	—
Vertical do.	·24	—
Transverse do.	·25	—
From optic nerve to outer or posterior margin of cornea	·27	·25
Do. to inner or anterior margin	·29	·19
Do. to upper margin	1·1	·24
Do. to lower margin	·25	·21
Transverse diameter of cornea	·20	·12
Vertical do.	·20	·11
Segment of cord of cornea	·16	—
Depth of curve	·7	—

One Eye of adult Lioness.—The eye had probably somewhat shrunk from having been for some time in dilute spirit.

Antero-posterior circumference, vertical	4·6
Do. horizontal	4·6
Transverse circumference	4·6
From centre of optic nerve to outer or posterior margin of cornea	1·18
Do. to inner or anterior margin	1·12
Do. to upper margin	1·20
Do. to lower margin	1·11
Transverse diameter of cornea	1·6
Vertical do.	1·5

Ten Eyes taken from five Cats.—Nos. 1 and 2 fully grown, but not old animals; No. 3, a fine but not fully grown cat; No. 4 was a very fine male, full grown.

	No. 1.	No. 2.		No. 3.		No. 4.	
	Both eyes alike.	Right.	Left.	Right.	Left.	Right.	Left.
Circumference, antero-posterior, vertical	2·16	2·18	2·19	2·16	2·16	2·17	2·19
Do. horizontal	2·16	2·17	2·18	2·16	2·16	2·17	2·18
Do. transverse	2·16	2·18	2·18	2·16	2·16	2·18	2·18
Diameter, antero-posterior	·26	·26	·26	·25	·25	·25	·25
Do. vertical	·26	·26	·26	·25	·25	·25	·25
Do. transverse	·26	·26	·26	·25	·25	·25	·25
From centre of optic nerve to outer margin of cornea	·27	·28	·29	·26	·26	·27	·28
Do. to inner margin	·24	·25	·26	·24	·25	·26	·25
Do. to upper margin	·27	·29	1·0	·28	·28	1·1	1·0
Do. to under margin	·24	·24	·24	·23	·23	·23	·24

	No. 1.	No. 2.		No. 3.		No. 4.	
	Both eyes alike.	Right.	Left.	Right.	Left.	Right.	Left.
Transverse diameter of cornea over curve	·24	·24	·25	·26	·25	·25	·25
Vertical do.	·23	·24	·24	·25	·25	·24	·24
Length of segment of cornea	·21	·19	·19	·20	·20	·20	·20
Depth of curve	·6	·9	·9	·8	·8	·8	·8

The eyes of a fifth cat were considerably smaller, but the proportions in the measurements were exactly the same as No. 1.

The cats were destroyed by hydrocyanic acid, which in all produced violent convulsions: the eyes were instantly removed. The cornea in all was found particularly prominent, which the mode of death will probably account for. The right eye of No. 2 was not removed and measured until two and a half hours after death, while the left was, even before the convulsions had ceased, which will perhaps account for the difference in size found in them. This opinion is confirmed by the fact that twelve hours after the eye had been taken out, it had become somewhat flaccid, and the antero-posterior diameter reduced from $\frac{26}{30}$ to $\frac{24}{30}$ of an inch, while the transverse diameter remained $\frac{26}{30}$.

FOUR EYES TAKEN FROM TWO BULLOCKS AND A CALF.—Warm when measured.

	Calf.	Bullock.	Right, of the same bullock.	Left, of the same bullock.
Antero-posterior circumference, vertical	4·0	4·17	4·24	4·23
Do. do. horizontal	4·0	4·17	4·23	4·21
Transverse do.	4·8	5·0	5·3	5·4
Diameter, antero-posterior	—	1·12	1·13	1·13
Do. vertical	—	—	1·20	1·20
Do. horizontal	—	1·18	1·19	1·19
From centre of optic nerve to outer or posterior margin of cornea	1·10	1·10	1·11	1·12
Do. to inner or anterior margin of cornea	1·15	1·18	1·22	1·22
Do. to upper margin	1·28	2·7	2·10	2·10
Do. to lower margin	1·6	1·10	1·12	1·12
Transverse diameter of cornea	1·5	1·18	1·13	1·14
Vertical do.	·26	1·1	1·1	1·1
Depth of inner or larger end of cornea	—	·27	1·0	1·1
Depth of outer or narrower end	—	·23	·24	·23
Length of cord of cornea	—	1·2	1·5	1·5
Depth of curve of cornea	—	·12	·13	·13

FIVE EYES TAKEN FROM THREE SHEEP.

	No. 1.	No. 2.		No. 3.	
		Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	3·15	3·22	3·22	3·14	3·14
Do. horizontal	3·15	3·22	3·22	3·15	3·15
Transverse circumference	3·22	4·2	4·2	3·21	3·21
Diameter, antero-posterior	1·2	1·6	1·6	1·2	1·2
Do. vertical	1·4	1·7	1·7	1·5	1·5
Do. horizontal	1·6	1·8	1·8	1·6	1·5
From centre of optic nerve to outer or posterior margin of cornea	1·0	1·6	1·7	·26	·25
Do. to inner or anterior margin	1·6	1·4	1·6	1·2	1·2
Do. to upper margin	1·24	1·27	1·27	1·12	1·12
Do. to lower margin	1·0	1·0	1·0	1·0	1·0

	No. 1.	No. 2.		No. 3.	
		Right.	Left.	Right.	Left.
Transverse diameter of cornea	1·3	1·5	1·3	1·4	1·1
Vertical do.	·25	·25	·25	·23	·21
Depth of large or inner end of cornea	·23	·20	·20	·21	·21
Do. narrow or outer end	·16	·16	·16	·15	·16
Length of cord of cornea	·27	·29	·29	·26	·24
Depth of curve of cornea	·9	·8	·8	·10	·10

Two Eyes taken from a Mare, 15 years old.—Both eyes measured exactly alike in all directions, except that the left cornea was $\frac{2}{30}$ of an inch deeper than the right.

Circumference, antero-posterior	5·22
Do. horizontal	5·25
Do. transverse	6·8
Diameter, antero-posterior	1·27
Do. vertical	1·28
Do. transverse	2·2
From centre of optic nerve to outer or posterior margin of cornea	1·25
Do. to inner or anterior margin	1·24
Do. to upper margin	1·29
Do. to lower margin	1·15
Do. along outer or posterior side to centre of cornea	2·19
Do. along inner or anterior side to do.	2·18
Do. along upper side to do.	3·14
Do. along lower side to do.	2·7
Horizontal diameter of cornea	1·18
Vertical do. in centre	1·8
Do. do. near inner margin	·28
Do. do. near outer margin	·23
Length of cord of cornea	1·12
Depth of curve of cornea	·12

Four Eyes taken from two Hares.

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	2·13	2·13	2·15	2·15
Do. do. horizontal	2·14	2·14	2·19	2·19
Transverse do.	2·16	2·16	2·22	2·23
Antero-posterior diameter	·23	·23	·25	·26
Vertical do.	·23	·23	·26	·24
Horizontal do.	·25	·24	·27	·27
From centre of optic nerve to outer or posterior margin of cornea	·23	·23	·23	·24
Do. to inner or anterior margin	·23	·24	·25	·27
Do. to upper margin	·20	·20	·23	·22
Do. to lower margin	·29	·29	1·0	1·1
Transverse diameter of cornea	·25	·25	·26	·25
Vertical do.	·23	·25	·25	·23
Length of cord of cornea	·20	·20	·21	·21
Depth of curve of cornea	·6	·6	·7	·7

Four Eyes taken from two Rabbits.

	No. 1, large.		No. 2, smaller.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	2·8	2·8	2·2	2·2
Do. do. horizontal	2·8	2·8	2·1	2·2
Transverse circumference	2·10	2·10	2·3	2·3
Antero-posterior diameter	·21	·21	·21	·20

	No. 1, large.		No. 2, smaller.	
	Right.	Left.	Right.	Left.
Vertical diameter	·21	·21	·21	·20
Horizontal do.	·22	·22	·21	·20
From centre of optic nerve to outer or posterior margin of cornea	·17	·17	·16	·17
Do. to inner or anterior margin	·25	·25	·23	·22
Do. to upper margin	·21	·23	·18	·17
Do. to lower margin	·22	·21	·24	·24
Transverse diameter of cornea	·25	·25	·23	·23
Vertical do.	·24	·24	·22	·21
Length of cord	·18	·18	·15	·16
Depth of curve	·6	·6	·7	·7

TWO EYES FROM SQUIRREL. (*Sciurus vulgaris.*)

	Inches.	
	Right eye.	Left eye.
Antero-posterior circumference, vertical	1·6	1·5
Do. do. horizontal	1·5	1·5
Transverse do.	1·8	1·8
Diameter, antero-posterior	·11	·11
Do. vertical	·11	·11
Do. horizontal	·12	·12
From centre of optic nerve to outer or posterior margin of cornea	·12	·12
Do. do. to inner or anterior margin	·12	·12
Do. to upper margin	·10	·10
Do. to lower margin	·15	·15
Cornea circular, vertical and horizontal diameters alike	·11	·11
Length of cord of segment	·10	·10
Depth of curve nearly	·3	·3

FOUR EYES FROM TWO RATS (brown), (*Mus decumanus,*) *in* 60*th of inch.*

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	·46	·47	·48	·48
Do. do. horizontal	·45	·47	·48	·48
Transverse circumference	·47	·48	·48	·48
Antero-posterior diameter	·15	·15	·16	·16
Vertical do.	·16	·16	·16	·16
Horizontal do.	·16	·16	·16	·16
From optic nerve to outer margin of cornea	·12	·12	·13	·13
Do. to inner margin	·14	·14	·13	·13
Do. to upper margin	·12	·12	·12	·12
Do. to lower margin	·13	·13	·13	·13
Cornea circular	·22	·22	·24	·24
Length of cord	·14	·14	·14	·14
Depth of curve	·7	·7	·7	·7

TEN EYES FROM FIVE FOWLS.—In each fowl the two eyes measured exactly alike, except that the corneæ were not perfectly circular in all cases. No. 1 was a very large Cochin cock; No. 2, also a Cochin cock, but not quite so large; Nos. 3 and 4, common young cocks; and No. 5, a hen; by which it is seen there is considerable variation not only in the size of the eyes, but in the position of the optic nerve.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Antero-posterior circumference, vertical	2.3	1·25	2·3	2·0	1·29
Do. horizontal	2·5	1·26	2·5	2·0	1·28
Transverse circumference	2·15	2·3	2·14	2·8	2·2

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.
Antero-posterior diameter	—	·17	·18	·16	·16
Horizontal do.	—	·23	·23	·22	·22
Transverse do.	—	·23	·23	·22	·21
From centre of optic nerve to outer or posterior margin of cornea	·20	·23	·21	·24	·20
Do. to inner or anterior margin	1·1	·22	·28	·21	·28
Do. to upper margin	—	·28	1·0	·27	·28
Do. to lower margin	—	·17	·18	·18	·19
Transverse diameter of cornea	·14	·13	·15	·15	·12
Vertical do.	·14	·12	·15	·14	·12
Length of cord of cornea	—	·10	·11	·11	·10
Depth of curve	—	·4	·3	·4	·3

FOUR EYES TAKEN FROM TWO TURKEYS. (*Meleagris Gallopavo.*)

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	2·20	2·21	2·23	2·24
Do. do. horizontal	2·21	2·20	2·23	2·24
Transverse circumference	3·3	2·4	3·6	3·5
Diameter, antero-posterior	·23	·22	·23	·23
Do. vertical	1·0	1·0	1·0	1·0
Do. horizontal	1·0	1·0	1·1	1·0
From centre of optic nerve to outer or posterior margin of cornea	·27	·28	·28	·29
Do. to inner or anterior margin	1·6	1·4	1·8	1·7
Do. to upper margin	1·7	1·6	1·10	1·10
Do. to lower margin	·26	·27	·27	·27
Transverse diameter of cornea	·17	·17	·17	·17
Vertical do.	·17	·17	·17	·16
Length of cord of segment	·14	·15	·15	·15
Depth of curve	·6	·6	·6	·6

TWO EYES TAKEN FROM GUINEA-FOWL. (*Numida Meleagris.*)

Antero-posterior circumference, vertical	1·27
Do. do. horizontal	1·20
Transverse circumference	2·5
Diameter, antero-posterior	·16
Do. horizontal	·20
Do. transverse	·20
From centre of optic nerve to outer or posterior margin of cornea	·24
Do. to inner or anterior margin	·20
Do. to upper margin	·28
Do. to lower margin	·17
Transverse diameter of cornea	·13
Vertical do.	·13
Length of cord of cornea	·11
Depth of curve of cornea	·4

FOUR EYES FROM TWO RED GROUSE OR PTARMIGAN. (*Tetrao Scoticus.*) Young birds.

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	1·19	1·19	1·19	1·19
Do. do. horizontal	1·20	1·19	1·21	1·20
Circumference, transverse	1·28	1·28	1·28	1·29
Diameter, antero-posterior	·14	·14	·14	·14
Do. vertical	·19	·19	·19	·19

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Diameter, horizontal	·20	·20	·20	·19
From optic nerve to outer or posterior margin of cornea	·18	·18	·18	·18
Do. to inner or anterior margin	·20	·20	·22	·21
Do. to upper margin	·23	·22	·22	·23
Do. to under margin	·15	·16	·16	·15
Transverse diameter of cornea	·11	·10	·11	·11
Vertical do.	·10	·9	·10	·10
Length of cord of segment of cornea	·9	·9	·9	·9
Depth of curve of cornea	·2	·2	·5	·6

THREE EYES TAKEN FROM TWO PARTRIDGES. (*Perdix cinerea.*) Both young birds; two eyes of one, right eye of another.

	No. 1.		No. 2.
	Right.	Left.	Right.
Antero-posterior circumference, vertical	1·12	1·12	1·12
Do. do. horizontal	1·14	1·15	1·14
Circumference, transverse	1·21	1·22	1·22
Diameter, antero-posterior	·12	·13	·14
Do. vertical	·17	·16	·17
Do. horizontal	·17	·17	·17
From optic nerve to outer or posterior margin of cornea	·15	·14	·15
Do. to inner or anterior margin	·19	·19	·18
Do. to upper margin	·19	·19	·19
Do. to lower margin	·14	·14	·14
Transverse diameter of cornea	·9	·9	·9
Vertical do.	·8	·8	·8
Length of cord of cornea	·7	·7	·8
Depth of curve of cornea	·5	·5	·6

FOUR EYES OF TWO ROOKS. (*Corvus frugilegus.*)

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Circumference, antero-posterior	1·27	1·28	1·29	1·28
Do. horizontal	1·29	1·29	1·29	1·29
Do. transverse	2·5	2·5	2·5	2·6
Diameter, antero-posterior	·17	·17	·17	·17
Do. vertical	·21	·21	·21	·21
Do. horizontal	·22	·22	·22	·22
From centre of optic nerve to posterior or outer margin of cornea	·20	·21	·22	·21
Do. to anterior or inner margin	·20	·21	·22	·21
Do. to upper margin	·26	·26	·27	·27
Do. to lower margin	·18	·19	·19	·18
From centre of optic nerve along posterior surface to centre of cornea	·27	·27	·27	·27
Do. along anterior to do.	·27	·27	·28	·28
Do. along upper to do.	1·1	1·2	1·2	1·3
Do. along lower to do.	·25	·25	·26	·25
Transverse diameter of cornea, good measure	·14	·14	·13	·13
Vertical do. bare measure	·14	·14	·13	·13
Length of cord of cornea	·11	·11	·10	·10
Depth of curve of cornea	·4	·4	·3	·3

TWO EYES FROM A CYGNET. Weighed 19 lbs. (*Cygnus olor.*)

	Inches.	
	Right.	Left.
Circumference, vertical	2·6	2·6
Do. horizontal	2·6	2·7

	Inches.	
	Right.	Left.
Circumference, transverse	2·18	2·19
Diameter, antero-posterior	·19	·19
Do. vertical	·25	·25
Do. horizontal	·26	·26
From optic nerve to outer or posterior margin of cornea	·25	·25
Do. to inner or anterior margin	·25	·25
Do. to upper margin	1·2	1·2
Do. to lower margin	·22	·22
Diameter of cornea, horizontal over curve	·15	·15
Do. vertical do.	·13	·13
Length of cord of segment	·13	·14
Depth of curve of cornea from edge of sclerotic plates	·8	·8

Two Eyes from a Goose (Domestic). (*Anser ferus.*)

	Right.	Left.
Antero-posterior circumference, vertical	2·5	2·5
Do. do. horizontal	2·6	2·6
Transverse circumference	2·16	2·15
Antero-posterior diameter	·20	·20
Vertical diameter	·25	·25
Horiozntal diameter	·25	·25
From centre of optic nerve to outer or posterior margin of cornea	·26	·26
Do. to inner or anterior margin	·24	·24
Do. to upper margin	1·0	1·1
Do. to lower margin	·19	·20
Horizontal diameter of cornea over curve	·15	·16
Vertical do. do.	·15	·14
Length of cord of segment of cornea (horizontal)	·12	·13
Depth of curve of cornea	·5	·5

Four Eyes from two Ducks (common Domestic). (*Anas Boschas.*)

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Antero-posterior circumference, vertical	1·23	1·23	1·22	1·22
Do. do. horizontal	1·26	1·24	1·24	1·23
Transverse circumference	2·1	2·0	2·0	2·0
Diameter, antero-posterior	·16	·17	·17	·17
Do. vertical	·19	·19	·19	·19
Do. transverse	·20	·19	·20	·19
Distance from optic nerve to outer or posterior margin of cornea, in line of entrance of nerve	·23	·23	·19	·19
Do. over centre of eye-ball	—	—	·18	·19
Do. to anterior or inner edge, in line of entrance of the nerve	·20	·19	·20	·20
Do. over centre of eye	—	—	·24	·23
Do. to upper edge	·24	·24	·24	·25
Do. to lower edge	·17	·16	·17	·17
Transverse diameter of cornea	·14	·13	·14	·14
Vertical do.	·13	·14	·13	·13
Length of cord of cornea	·11	·11	·11	·11
Depth of curve	·4	·4	·4	·4

Three Eyes from two Green Turtles. (*Testudo mydas.*)

	No. 1. weighed 70 lbs.		No. 2. about 50 lbs.
	Right.	Left.	Right.
Circumference, antero-posterior, vertical	3·5	3·4	2·24
Do. do. horizontal	3·9	3·9	2·25

	No 1. weighed 70 lbs. Right.	No 1. weighed 70 lbs. Left.	No. 2. about 50 lbs. Right.
Circumference, transverse	3·18	3·17	3·4
Diameter, antero-posterior	·24 & ·26	·24 & ·26	·19 & ·23
Do. horizontal	1·4	1·4	·29
Do. transverse	1·6	1·6	1·1
From optic nerve to outer or posterior margin of cornea	1·13	1·16	1·7
Do. to inner or anterior margin	1·9	1·11	1·2
Do. to upper margin	1·27	1·26	1·18
Do. to under margin	·28	1·0	·27
Diameter of cornea, transverse	·10	·10	·11
Do. vertical	·8	·9	·8

The cornea is rather sunken than projecting; the lens is nearly spherical, but a little flattened on its anterior and posterior surfaces, though very little on the latter. The vitreous humour is soft. The sclerotic is composed of cartilage, with a little fibre from the muscles and cellular envelope. It contains a rim of bony plates, and it is very irregular in form at the posterior surface, the antero-posterior diameter at the entrance of the optic nerve being much less than the corresponding point above; thus, in the largest turtle, at the optic nerve, it is $\frac{24}{30}$ of an inch; above, $\frac{26}{30}$: in the smaller, at nerve, $\frac{19}{30}$; above, $\frac{23}{30}$. The optic nerve is small, its sheath thin, and not much connected with the sclerotic; indeed, where this is cartilaginous in most creatures it is so, it being only in those who have a fibrous sclerotic that the sheath of the nerve is lost in it.

ONE EYE FROM ALLIGATOR (four feet long).

Antero-posterior circumference	2·21
Transverse do.	2·27
Antero-posterior diameter	·26
Transverse do.	·29
From centre of optic nerve to outer or posterior margin of cornea	·26
Do. to inner or anterior margin	·28
Do. to upper margin	1·6
Do. to lower margin	·24
Transverse diameter of cornea	·23
Vertical do.	·21

TEN EYES FROM THREE TOADS (*Bufo vulgaris*) AND TWO FROGS (*Rana temporaria*).

In each, the two eyes measured alike; one toad, No. 3, was one of the largest I ever saw, measuring round the body five and a half inches, and from toe to jaw seven and a half inches; the other two and the frogs were average size adults. The measurements are in 60ths of an inch.

	Toads.			Frogs.	
	No. 1.	No. 2.	No. 3.	No. 1.	No. 2.
Antero-posterior circumference, vertical	·54	·50	·53	·48	·48
Do. do. horizontal	·54	·50	·56	·48	·48
Transverse circumference	·58	·52	·58	·50	·50
Antero-posterior diameter	·18	·16	·17	·16	·16
Vertical do.	·19	·16	·17	·16	·16
Horizontal do.	—	·17	·19	·17	·18
From optic nerve to outer or posterior margin of cornea	·19	·18	·20	·16	·16
Do. to inner margin	·20	·18	·20	·16	·16
Do. to upper margin	·23	·22	·24	·19	·19
Do. to lower margin	·17	·15	·18	·15	·14

	Toads.			Frogs.	
	No. 1.	No. 2.	No. 3.	No. 1.	No. 2.
Transverse diameter of cornea	·16	·15	·16	·18	·18
Vertical do.	·13	·13	·14	·15	·15
Length of cord of cornea	·13	·13	·14	·16	·16
Depth of curve	·4	·4	·4	·4	·4

ONE EYE FROM CHAMELEON, rather small in size.

Antero-posterior circumference, vertical	1·2
Do. do. horizontal	1·0
Transverse circumference	1·3
Diameter, antero-posterior	·11
Do. vertical	·10
Do. horizontal	·11
From optic nerve to outer or posterior margin of cornea	·11
Do. to inner or anterior margin	·10
Do. to upper margin	·17
Do. to lower margin	·10
Transverse diameter of cornea	·4
Vertical do.	·4
Length of cord of cornea	·3
Depth of curve	·1

FISH.

FOUR EYES FROM TWO HALIBUT. (*Hippoglossus vulgaris.*) In No. 1 fish, both eyes measured exactly alike; but in No. 2, there was a considerable difference, the right eye being, in most of its dimensions, considerably less than the left, occasioned by a deep sulcus-like depression in the sclerotic; the lens also was decidedly smaller than that of the left eye, but it was also more dense (see weight of lens).

	No. 1.	No. 2.	
	Both eyes alike.	Right.	Left.
Antero-posterior circumference	2·23	3·15	3·23
Horizontal do.	3·10	4·0	3·29
Transverse do.	3·10	3·27	4·2
Antero-posterior diameter	·25	1·2	1·3
Vertical do.	·29	1·8	1.7
Transverse do.	1·4	1·11	1·11
From centre of optic nerve to outer or posterior margin of cornea	·27	1·3	1·4
Do. to inner or anterior margin	1·12	1·17	1·17
Do. to upper margin	1·14	1·19	1·20
Do. to lower margin	·23	·29	·29
Transverse length of cornea	·25	1·1	1·1
Vertical do.	·18	·25	·25

TWO EYES FROM SOLE. (*Solea vulgaris.*)

	Both eyes alike.
Antero-posterior circumference, vertical	1·1
Do. do. horizontal	1·11
Transverse do.	1·10
Antero-posterior diameter	·10
Vertical do.	·11
Horizontal do.	·13
From centre of optic nerve to outer or posterior margin of cornea	·12
Do. to inner margin	·15
Do. to upper margin	·13
Do. to lower margin	·8
Transverse diameter of cornea	·12
Vertical do.	·10

Two Eyes from Salmon.—(*Salmo solar.*)

	Eyes alike.
Antero-posterior circumference, vertical	2·6
Do. horizontal	2·6
Transverse do.	2·11
Diameter, antero-posterior	·15
Do. vertical	·22
Do. horizontal	·23
From centre of optic nerve to outer or posterior margin of cornea	·22
Do. to inner or anterior margin	·26
Do. to upper margin	·23
Do. to lower margin	·27
Transverse diameter of cornea	·17
Vertical do.	·16
Length of cord of cornea	·15
Depth of curve of cornea	$\frac{1}{40}$

The optic nerve enters the sclerotic as a broad ribband, the broad surface horizontal. The eyes are placed forwards in the head, which is sharp, almost pointed, and probably allows the eyes to be directed somewhat to the same object when placed before the creature. Outline of sclerotic, as in most fish, very irregular.

Two Eyes from Salmon Trout.—(*Salmo trutta.*)—Weighed two pounds.

	Right.	Left.
Circumference, antero-posterior	1·17	1·17
Do. horizontal	1·19	1·19
Do. transverse	1·25	1·24
Diameter, antero-posterior	·11	·11
Do. vertical	·17	·17
Do. horizontal	·18	18
From centre of optic nerve to outer or posterior margin of cornea	·15	·15
Do. to inner or anterior margin	·21	·20
Do. to upper margin	·16	·15
Do. to lower margin	·17	·18
Transverse diameter of cornea	·14	·14
Vertical do.	·13	·13

Cornea very nearly flat.

The sclerotic is imbedded in a mass of oily fat, which closely surrounds it. The optic nerve is very flat; the sclerotic almost pure cartilage.

Two Eyes from Trout.—(*Salmo vulgaris.*) 4½oz. weight. Greyling.—(*Thymallus vulgaris.*) 5oz. weight.

	Trout.	Greyling.
Antero-posterior circumference, vertical	1·2	1·4
Do. do. horizontal	1·4	1·5
Transverse circumference	1·8	1.8
Diameter, antero-posterior	·7	·9
Do. vertical	·11	·12
Do. horizontal	·13	·13
From optic nerve to outer or posterior margin of cornea	·10	·12
Do. to inner or anterior do.	·13	·14
Do. to upper margin	·10	·11
Do. to lower margin	·11	·12
Diameter of cornea, transverse	·13	·10
Do. vertical	·12	·9

Two Eyes from Dace.—(*Cyprinus leuciscus.*) 5oz weight. Golden Carp.—(*Cyprinus auratus.*) 4½ inches long.

	Dace.	Carp.
Antero-posterior circumference, vertical	0·28	0·22
Do. do. horizontal	0·28	·22

	Dace.	Carp.
Transverse circumference	1·2	·24
Diameter, antero-posterior	·7	·6
Do. vertical	·10	·7
Do. horizontal	·11	·7
From optic nerve to outer or posterior margin of cornea	·9	$\cdot\frac{15}{60}$
Do. to inner or anterior margin	·10	·17
Do. to upper margin	·8	·16
Do. to lower margin	·10	·16
Diameter of cornea, transverse	$\cdot\frac{16}{60}$	·13
Do. vertical	$\cdot\frac{15}{60}$	·12

Two Eyes from Mackerel.—(*Scomber scomber.*)

	Right.	Left.
Antero-posterior circumference, vertical	1·22	1·21
Do. do. horizontal	1·24	1·23
Transverse circumference	1·29	1·29
Diameter, antero-posterior	·14	·14
Do. vertical	·19	·19
Do. transverse	·20	·20
From optic nerve to outer or posterior margin of cornea	·15	·15
Do. to inner or anterior do.	·24	·23
Do. to upper margin	·18	·19
Do. to lower margin	·18	·19
Diameter of cornea, horizontal	·14	·16
Do. vertical	·15	·14

The sclerotic is very irregular and lobulated in outline.

Two Eyes from common Herring.—(*Clupea harangus.*)

	Right.	Left.
Antero-posterior circumference, vertical	1·14	1·14
Do. do. horizontal	1·14	1·14
Transverse circumference	1·22	1·22
Diameter, antero-posterior	·11	·11
Do. vertical	·18	·18
Do. transverse	·18	·18
From optic nerve to outer or posterior margin of cornea	·11	·12
Do. to inner or anterior do.	·18	·18
Do. to upper margin	·16	·14
Do. to lower margin	·14	·14
Diameter of cornea, horizontal	·17	·16
Do. vertical	·16	·16

Sclerotic irregular, but not to the same extent as in the mackerel. The cornea is very large, and, as in many fish, the boundary between it and the sclerotic not distinct.

Four Eyes from Sand Dab (*Platessa limanda*) and Venom Fish, Little or Common Weever (*Trachinus vipera*).

	Sand Dab.		Weever.
	Right.	Left.	Both eyes alike.
Circumference, antero-posterior, vertical	·29	·29	·20
Do. do. horizontal	1·4	1·3	·21
Do. transverse	1·2	1·3	·23
Diameter, antero-posterior	·8	·8	·6
Do. vertical	·10	·11	·7
Do. horizontal	·12	·12	·8

	Sand Dab. Right.	Sand Dab. Left.	Weever. Both eyes alike.
From optic nerve to outer or posterior margin of the cornea	·9	·9	·5
Do. to inner margin	·14	·13	·9
Do. to upper margin	·14	·13	·5
Do. to lower margin	·8	·7	·8
Transverse diameter of cornea	·12	·11	·6
Vertical do.	·9	·9	·6

The sand-dab is a small flat fish, very like the sole in shape, with the eyes placed very obliquely.

The viper fish is a curious, small (not more than five inches long), very active, and strong fish, living several hours after being taken out of the water. He is said to conceal himself in the sand, with only his head exposed. The fishermen regard him as exceedingly venomous; probably he is not so, but capable of inflicting a severe wound with the very sharp and strong spines of the dorsal fin, the use of which he knows perfectly well, for if taken hold of, he instantly with great force and suddenness curls himself round so as to strike with them. The eyes are placed at an acute angle, with only a very narrow strip of frontal bone between them, so as to command a large field upwards.

FOUR EYES TAKEN FROM TWO CODLINGS (young Cod).—(*Gadus morrhua.*)

	No. 1. Right.	No. 1. Left.	No. 2. Right.	No. 2. Left.
Circumference, antero-posterior, vertical	1·22	1·22	1·15	1·15
Do. do. horizontal	1·25	1·25	1·16	1·17
Do. transverse	1·28	1·28	1·22	1·21
Diameter, antero-posterior	·15	·14	·12	·12
Do. vertical	·18	·18	·16	·16
Do. horizontal	·19	·19	·17	·18
From optic nerve to outer or posterior margin of the cornea	·17	·18	·15	·15
Do. to inner or anterior margin	·19	·20	·17	·17
Do. to upper margin	·18	·18	·15	·14
Do. to lower margin	·17	·17	·14	·14
Transverse diameter of the cornea	·18	·17	·16	·16
Vertical do.	·17	·16	·15	·15

FOUR EYES TAKEN FROM A WHITING (*Merlangus vulgaris*) and BILLETT BALLENWRASSE (*Labius maculatus*).

	Whiting. Right.	Whiting. Left.	Billett. Right.	Billett. Left.
Circumference, antero-posterior, vertical	1·15	1·16	1·18	1·20
Do. do. horizontal	1·16	1·15	1·20	1·20
Do. transverse	1·20	1·20	1·26	1·26
Diameter, antero-posterior	·13	·12	·12	·12
Do. vertical	·16	·15	·17	·18
Do. horizontal	·16	·17	·19	·19
From optic nerve to outer or posterior margin of cornea	·15	·14	·15	·14
Do. to inner or anterior margin	·17	·17	·18	·18
Do. to upper margin	·15	·15	·15	·17
Do. to lower margin	·15	·17	·16	·15
Transverse diameter of the cornea	·15	·15	·16	·16
Vertical do.	·15	·15	·15	·16

FOUR EYES TAKEN FROM TWO LARGE COD.—(*Gadus morrhua.*)

	No. 1.		No. 2.	
	Right.	Left.	Right.	Left.
Circumference, antero-posterior, vertical	4·1	4·1	3·20	3·20
Do. do. horizontal	4·4	4·6	3·26	3·23
Do. transverse	4·12	4·12	4·6	4·6
Diameter, antero-posterior	1·4	1·4	·29	·29
Do. vertical	1·11	1·13	1·10	1·10
Do. horizontal	1·14	1·15	1·12	1·12
From centre of optic nerve to outer or posterior margin of cornea	1·8	1·7	1·5	1·5
Do. to inner or anterior margin	1·21	1·20	1·16	1·15
Do. to upper margin	1·13	1·12	1·8	1·9
Do. to lower margin	1·10	1·10	1·8	1·7
Transverse diameter of cornea	1·4	1·5	1·2	1·2
Vertical ditto	1·2	1·4	1·1	1·1
Length of cord of cornea	1·4	1·5	1·2	1·2
Depth of curve, none	—	—	—	—

EIGHT EYES TAKEN FROM FOUR HADDOCK.—(*Gadus æglefinus*).

	No. 1.		No. 2.		No. 3. Both Eyes.	No. 4. Both Eyes.
	Right.	Left.	Right.	Left.		
Circumference, antero-posterior, vertical	3·10	3·10	3·13	3·9	3·14	2·17
Do. horizontal	3·18	3·19	3·19	3·15	3·22	2·19
Do. transverse	3·27	3·27	3·23	3·23	4·1	2·27
Diameter, antero-posterior	·28	·28	·29	·29	1·1	·19
Do. vertical	1·4	1·5	1·4	1·3	1·10	·27
Do. horizontal	1·10	1·10	1·10	1·8	1·12	·29
From centre of optic nerve to outer or posterior margin of cornea	1·4	1·4	1·4	1·6	1·5	·26
Do. to inner or anterior margin	1·12	1·11	1·12	1·10	1·13	1·1
Do. to upper margin	1·3	1·4	1·5	1·5	1·8	·26
Do. to under margin	1·4	1·4	1·5	1·5	1·4	·29
Transverse diameter of cornea	1·0	1·0	·29	·29	1·5	·21
Vertical do.	·28	·26	·25	·25	1·1	·20
Cornea, flat	—	—	—	—	—	—

In No. 4 both eyes measured exactly alike in every direction, and also in No. 3, except that the transverse circumference of the left eye was larger than that of the right by $\frac{2}{30}$ of an inch.

The inner curve of the cornea in many fish is somewhat larger than the outer.

To these tables I shall have to refer hereafter (see Physiology of vision—Single vision with two eyes). I will therefore at present merely call attention to the fact that where the eye is not a true globe, the transverse diameter is, contrary to the common opinion, broader than the antero-posterior: that the cornea is in the great majority of animals not perfectly circular, being, even in those having circular pupils, commonly somewhat broader in the transverse than in the vertical direction; that there is not only a decided difference in the size of the eye-ball in animals of the same species, but that even in the same animal the two eye-balls are not always of precisely the same size: and that the entrance of the optic nerve is eccentric, not only horizontally, but vertically; and that the precise relations of the nerve and the ball of the eye differ considerably, not only in animals of different classes, but in those of the same species, and that even in the two eyes of the same creature, the correspondence is not invariably the same.

The EYE-BALL was formerly described as consisting of three coats,—the sclerotic, the choroid, and the retina; and of three humors, — the aqueous humor, the crystalline lens, and the vitreous humor; even now it is not an inconvenient method to follow this as a rough ground plan, with such subdivisions, as additions to and variations in structure render necessary.

The relative position and proportion of the different parts composing the eye is best shown in the magnified section constructed by Soemmerring, of which the annexed is a reduced and modified figure, being twice the natural dimension.

SCLEROTIC COAT.

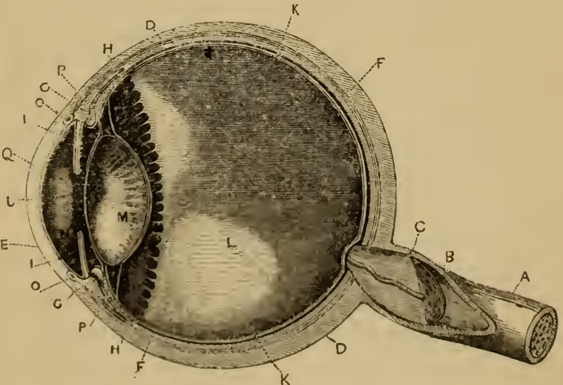

FIG. 83.

The sclerotic coat, with the cornea, by which it is completed anteriorly, forms the strong outermost protecting case of the eye-ball. Upon it the spheroidal form of the eye depends, as does also the integrity of the delicate and highly organized internal parts, which, but for the strong resisting sclerotic,

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Fig. 83 represents a perpendicular section through the antero-posterior diameter of the left eye.

A the optic nerve; B an oblique section of the nerve to show C, the central would, even by their own weight alone, soon fall to pieces. The sclerotic forms about five-sixths of the external wall of the globe; a little more or less according to the size of the cornea. The posterior part is perfectly spherical in man, but near the junction of it and the cornea, there is, at times, a slight flattening, which somewhat increases the apparent convexity of the cornea. This flattening in many animals is much more decided than it is in man, as in reptiles and birds, where there are bony plates. The sclerotic is considerably thicker at the posterior part than anteriorly. At the entrance of the optic nerve it is about one twenty-fourth of an inch thick, it gradually becomes thinner until its junction with the cornea, where it is not more than half this thickness, but as here it receives the insertions of the tendons of the four straight muscles, it is somewhat strengthened by them as they expand over and amongst its fibres; so that probably the weakest part of this coat is near the transverse diameter of the eye. Posteriorly it is so thick as to be nearly if not quite opaque by reflected light, but anteriorly it is translucent, and permits the black colour of the choroid within it to appear through, thus giving to this part of the eye that bluish tint, which is so evident in children, and particularly in delicate young females. Even the thicker posterior part is not so opaque as it has commonly been described, for if the pigment of the choroid is not intense there is no difficulty in perceiving the light of a candle through the eye, and in many eyes taken both from men and women I have distinctly seen the figure of an object interposed between a candle and the cornea thrown upon the translucent sclerotic behind.

The sclerotic coat consists principally of white fibrous tissue with more or less of the yellow elastic element mingled with it, the proportion of elastic fibres being greater towards the inner than the outer surface of the texture. The fibres are small and dense, but little waving; with an intricate intermingling, in

artery of the retina entering the eye; D D the sclerotic coat; E the cornea; F F the choroid coat; G G the ciliary circle, muscle, or ligament; H H the ciliary body,—pars non fimbriata; and ciliary processes,—pars fimbriata; I I the iris; J the pupil; K K the retina lying upon L, the vitreous humor; M the crystalline lens enclosed in its capsule; N the aqueous humor; O O the circular sinus or canal of Schlemm; P P the canal of Petit; Q the membrane of the aqueous chamber or membrane of Decemet.

which no very definite arrangement of them can be made out, but certainly with a prevailing course in curved lines from behind forwards, and so laid down that the elastic fibres have a constant tendency to slightly contract the dimensions of the coat, and thus exercise a gentle support upon the ocular contents, by which probably the due firmness and rotundity of the ball is maintained in health, and which is so essential to perfect vision. This tendency is easily seen by making a transverse section of the eye just behind the cornea, particularly the eye of any small mammalia, as in a monkey, hare, rat, or small dog, where the sclerotic is very thin; the cut edge will always be found to curl inwards, a tendency which is probably increased on account of there being a larger number of elastic fibres towards the inner than the outer surface of the coat. It has been thought by some that the outer fibres are more curved transversely, while the inner are rather directed forward, this may possibly be so, but this appearance certainly in part arises from the inner surface being marked with the more longitudinal lines of the choroid coat. A thin vertical section under the microscope shows the fibres, which present an irregular reticulated or network appearance throughout the whole coat, to be interlaced in every direction, leaving irregular interspaces. They contain many nuclei, which are rendered very distinct by acetic acid.

The exterior surface is rough, white, and cellular, from its connection to the parts amongst which it is placed. The internal surface is smooth and always stained with the pigment of the choroid coat, upon which it lies, and to which it is connected by very fine reticular tissue, constituting the *lamina externa seu fusca membranæ arachnoideæ.* Many slightly depressed longitudinal lines are always here observed, they mark the course of the ciliary nerves and long ciliary arteries; and various minute foramina are perceptible at the posteror part; these are for the passage of the ciliary arteries and nerves; and four or five larger oblique openings more anteriorly mark the situation of the veins in their course out of the globe. Anteriorly the sclerotic, just behind its junction with the cornea, is perforated by the anterior ciliary vessels, which are numerous and very small.

On the inner and under side of the antero-posterior axis, the optic nerve enters the sclerotic. The sheath of the nerve being continuous, both with the dura mater and sclerotic, formerly gave rise to the supposition of the latter being derived from the former tissue. The nerve at this point appears as though constricted, as if a string had been tied round it, and hence it is commonly described as narrowed on its entrance to the sclerotic, but this constriction only affects the sheath as it is about to coalesce with the sclerotic, and not the nerve itself, the fibrillæ of which are rather enlarged than not. There is not a single aperture, but a perforated plate—the *lamina cribosa,* containing many small foramina through which the nervous fibrillæ enter the ball. This part is best seen after slight decomposition has occurred, when by pressing upon the optic nerve, the nervous matter may be seen escaping by minute points of the size of the foramina. In the centre is one larger than the others, this is for the passage of the central artery of the retina.

Like most fibrous structures, the sclerotic is not highly organized, it is scantily supplied with blood-vessels and nerves, for though it gives passage to a great number of both, it receives but few itself. Nerves have been described, and doubtless exist, but their demonstration is a most difficult feat, which has only been doubtfully accomplished. The blood-vessels are more easy of proof. Ruysch, in his *Epistola tertia et decima de oculorum tunicis,* has a plate showing the vessels in a sclerotic, which he had injected ; and Arnold has two figures showing more numerous vessels, both arteries and veins, than Ruysch ;* but as in the healthy condition the vessels are exceeding small, it is not very easy to show them by injections. They are far more satisfactorily seen in an eye affected with iritis or sclerotitis, when the coat becomes almost crimson from the injection of the numerous vessels, which in health do not admit the red corpuscles ; these vessels are principally derived from the anterior and posterior ciliary arteries—doubtless however the majority of these vessels only pass through the sclerotic to the iris and ciliary processes, and in all probability the sclerotic derives most of its nutriment from very minute twigs which pass into its structure from the muscles and the cellular tissues with which it is in connection.

The junction of the sclerotic with the cornea is an important part of the eye, for it serves almost as a common point of attachment for other tissues, besides these two, as will be presently more particularly pointed out. The connection of the two tissues is so intimate as to render separation, without division of structure, impossible; much interest has attached to the exact mode in which the union of the two occurs; it has been generally described as effected by the two tissues being bevelled off in contrary directions, so that an oblique attachment is allowed, but there is no general agreement amongst anatomists as to whether the anterior or posterior edge of the cornea is the one to be bevelled off; the anterior being said to be that most commonly so; by some, however, it is asserted that the vertical and horizontal edges are reversed in this respect, hence the departure from a circular figure in the cornea; some again describe the cornea as being set into a depression in the edge of the sclerotic, as a watch-glass into its frame. It is highly probable, indeed may, I think, be stated as a fact, that in different eyes there is a difference in the direction of the sloping of the two tissues. In most the outer edge of the sclerotic is prolonged upon the cornea, in some this is much less apparent, and indeed is reversed, while occasionally the cornea is received into a groove in the sclerotic as a watch-glass into the metallic ring, in which case the inner rim is always less deep than the outer. This difficulty has however been set at rest by the microscope, and the interest of it much lessened by the substitution of another, by which is clearly shown the wonderful fact, that the two tissues, dissimilar as they are to the unaided eye, are in reality one continuous structure, the irregular fibres of the opaque sclerotic being modified into the perfectly transparent laminæ of the cornea; thus realizing the correctness of the older names transparent and opaque cornea; though of course they who bestowed them were unacquainted with this continuation of tissue, which nothing but the microscope could have demonstrated. Plate 1.

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* Arnold, Icones Organ. Sensuum. Plate 2, figs. 8 and 9.

The tendons of the four recti muscles, before being inserted into the sclerotic, spread out and assist in giving the lustrous pearly appearance to the white of the eye—the *tunica albuginea* as it has been called. That the muscles exercise some pressure upon the eye-ball in the course of their passage upon it is evident in cases of disease; both where the humors are so increased as to dilate the ball, when a bulging is then seen between the muscles, and also where the humors are diminished in quantity, and it collapses, when a somewhat quadrilateral form is given to it by the muscles. The tendinous fibres of the muscles, which pass into the sclerotic coat, become mingled and lost in its proper tissue, but some of them may be traced running forwards in the middle of it, in some cases as far as the cornea, and in one case I thought I could trace an appearance as though prolonged upon the edge of the cornea itself, as was asserted by Horne.

In mammalia the sclerotic coat is fibrous, but in other classes of animals it is more or less cartilaginous. In birds, the common fowl for instance, it consists of an inner cartilaginous layer in which the cells are regular in size and arrangement, containing one, two, or several nuclei, and an outer layer of white fibrous tissue. Plate 1.

In reptiles, as the alligator, frog, and toad, there is a complete inner cartilaginous and outer fibrous layer; the cartilage cells being very large and distinct in the thick posterior portion of the coat in the toad.

In most fish the sclerotic is pure cartilage, in others there is an inner thick cartilaginous layer with a tolerably complete thin external layer of white fibrous tissue, as in the haddock, sole, and holibut, while in others, as the trout, the fibrous layer is partial and seen principally about the attachment of the muscles, as though derived from their tendons, the other parts of the sclerotic consisting entirely of cartilaginous cells. In the sturgeon there is a firm thick cartilaginous cup imbedded within a strong fibrous sclerotic, but nearer to the inner than the outer surface; while in other fish, as the sword-fish, the sclerotic is a dense unyielding cup of bone.

CORNEA.

The cornea forms about one-sixth part of the exterior tunic of the eye, a little more or less according to the diameter of the eye and the size of the cornea. It is not usually perfectly circular, though generally described as such; occasionally it is so, but in the great majority of cases the transverse diameter is greater than the vertical.*

The transverse diameter, measured over the curve, varies from 11-30ths of an inch, the smallest adult cornea I have measured, to 18-30ths, the largest; while the vertical diameter varies from 11-30ths to 16-30ths; the ordinary size of the transverse being sixteen or seventeen thirtieths, and of the vertical diameter fourteen or fifteen thirtieths. Occasionally there is a slight difference in the size of the two corneæ. It is stated by some that the inner side of the cornea is broader than the outer; in many animals, where there is a great disproportion between the horizontal and vertical diameter of the cornea, there is a considerable difference in the depth of the inner and outer side of the cornea, as the foregoing tables show, but I have not usually observed such inequality in man, nor that the inner margin is a segment of a true circle, while the outer margin is of an ellipse, as the usual shape, as thought by Haller and Dalrymple. In some corneæ it certainly does occur, but these I think are to be regarded as the exceptions rather than the rule. In most, if not in all animals, however widely the *external* surface of the cornea departs from the circular form, the *internal* surface is a *true or nearly true circle,* as in the horse, ox, and sheep, for instance, a fact which, so far as I know, has hitherto escaped notice. This want of agreement in shape of the two surfaces of the corneæ obviously has no relation to the proper function of the cornea as a transparent aperture regulating the size and direction of the rays of light admitted to the eye, for the outer surface being opaque the transparency of the inner is of no moment; but it has, I believe, an interesting and most important anatomical relation to other structures, as I shall hereafter point out.

The cornea is a segment of a smaller sphere than the sclerotic. The cord of the segment is from 13-30ths to 15-30ths of an inch

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* Not only are there individual variations in the size of the cornea, but the size of it in proportion to the size of the eye varies very greatly in different genera of animals, the size being apparently regulated by the range of vision, and the degree of light admitted to the eye. Where the light is feeble, usually the corneal opening is large, as in nocturnal animals, and in fish which live in deep water, where the light is necessarily weak: so also where the range of vision is considerable, as in many birds and timid animals which are preyed upon, the cornea is commonly large.

long, and the projection of the curve about 4-30ths from this line. Various estimates have been formed of the relative size of the spheres of which the cornea and sclerotic form parts. Maitre Jean thought that of which the cornea is a segment is only one-eighth part less than that of the sclerotic; Huyghens, that the diameter of the two is as three to five, and Petit as seven to eleven. These two estimates are nearly the same and probably near the truth, but perhaps make the difference rather too great, while the calculation of Maitre Jean is certainly not sufficient; seven to twelve being as nearly the proportion as I can measure. Indeed it is more than probable than the convexity of the cornea differs not only in different people, but in the same person at different periods of life; being in youth permanently more convex than in old age, and, temporarily, at all ages, according to the pressure of the recti muscles; hence attempts at very minute measurement are not of much practical importance. The outer surface of the cornea is usually less extensive than the inner, in consequence of the irregular reticular arrangement of the fibres towards the external surface of the sclerotic being continued further forwards than those towards the inner surface, as has already been mentioned.

The cornea in different persons varies considerably in its thickness, in some being little more than half the thickness it is in others. Soemmerring declares that the tunics are thinner in large eyes than in small. "Magni bulbi tenuìoribus plerumque tunicis sunt, quam parvi."* An observation which, however, I should regard as by no means in the light of an axiom, but as liable to many exceptions. The cornea is however much thicker than the anterior portion of the sclerotic, with which it is continuous, not differing much from the thickest posterior part: the average being about the 1-25th of an inch. In the fœtus the cornea is much thicker than any part of the sclerotic.† It is of uniform thickness throughout its extent, and not thicker at its central portion as has been not unfrequently supposed. True it is that if macerated in water, and in some cases without this, by mere imbibition of the aqueous humor after death, when examined it is found to be thicker in the middle than towards the margin; but this is merely a post mortem and mechanical effect, owing to the laminæ of which its fibrous portion consists not being so firmly connected together in the centre as at the sides, and thus a larger amount of fluid is here absorbed, and the tissues more distended; but if the cornea be subjected to careful examination immediately after the death of the creature, I believe neither in man nor in any adult animal will it be found that the two surfaces depart from parallelism.* By some anatomists and mathematicians the cornea has been supposed to be a meniscus, and by M. Chopet, who took great pains to measure its two surfaces, it was thought to be an ellipsoid of such a curve as to refract parallel rays of light to a focus with mathematical accuracy. That it does refract rays when its concavity is filled up with the aqueous humour or with water is certain, but that it does so when in air and both surfaces dry is more than doubtful: if wet, it certainly does; but as Mr. Bowman has correctly remarked, this arises from its being held horizontally and the water gravitating to the central and then lowest portion of the cornea, and thus converting it into a lens; if held in a vertical position no such effect is observed.

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* Icones Oculi Humani, tabula quinta.

† This difference in the thickness of the cornea is of great practical importance to the surgeon in the operation of extracting an opaque lens, as the amount of force and in consequence in some degree the direction of the knife, in making the corneal section, will vary in accordance with the resistance of the cornea. In operating upon two consecutive cases it will sometimes be found that almost twice the force is necessary to make the section of the cornea in one, as is sufficient in the other, in consequence of its greater thickness, and I believe also firmness.

The cornea, which in the healthy living condition is one of the most transparent substances in nature, soon after death becomes more or less opaque, apparently merely from an alteration in the relation of its solid and liquid molecules. Simple pressure causes a depression and opacity, the transparency returning as the former disappears on the removal of the pressure; and also absorption of more fluid by immersion in water impairs the transparency, which returns as the fluid escapes. It is also rendered completely and permanently opaque by all those reagents which act upon albumen.

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* It may however be mentioned that in the Museum of the College of Surgeons of England there is the preparation of a cornea, No. 1781, of I think a whale, put up to show the cornea as thicker in the middle part than at the margin, like a double convex lens.

The cornea consists of three distinct structures, an outer conjunctival; a middle, the proper corneal tissue; and an internal, elastic, layer.

The *outer layer* is a continuation of the sclerotic conjunctiva, which becomes so closely attached to the margin of the cornea at its junction with the sclerotic; so much thinner and more delicate in its structure, with so little of the fibrous basement membrane; and so closely connected to the surface of the true cornea; that formerly anatomists were not agreed as to its existence or not. I think now for reasons before given, no doubt can be felt as to its existence. Though the best injected preparations fail to show any vessels passing over the cornea, and do show a plexiform looping of the conjunctival vessels upon the edge of it beyond which no injection can be made to pass (see figure of these vessels in the Cat and Rook, plate iv.), it appears highly probable from the facility with which it becomes congested that it is vascular in its normal condition; and the intense pain which is instantly caused by any small sharp particle getting upon or imbedded within it, clearly shows the presence of nerves. The epithelial scales are freely cast off and rapidly renewed by the formation of a new under layer which presses outwards those already existing. The *middle* part forms by far the greater portion of the cornea, it is a true continuation of the white fibres of the sclerotic, but in which the fibres have assumed a nearly parallel course, in somewhat curved layers, which constitute the laminæ into which the cornea is so readily separated after immersion in boiling water, or after putrefaction has somewhat advanced. Attempts have been made to determine the number of these layers; this it is almost impossible to do with accuracy, for the individual lamellæ do not extend uninterruptedly throughout the cornea. Mr. Bowman has calculated the number at any one part of a vertical section at sixty, but in the bullock I have counted at least one hundred and twenty. So also the manner in which these lamellæ are connected together is open to doubt; Dalrymple and the majority of anatomists describe it as by very delicate cellular tissue, the interstices of which are filled with fluid; while Bowman considers there is no fluid present, and that the connexion is by similar vertical lamellæ, but more delicate than the horizontal, which he thinks to satisfactorily explain the cause of the fact so long known, that the cornea is far stronger and more resistant in the horizontal—in the plane of the lamellæ, than the vertical direction. According to my observation, neither of these descriptions is quite correct. It appears to me, after the most careful investigation I can make upon the corneæ of different animals, in various stages of freshness and decomposition, and the application of different reagents, that the arrangement and connexion of these laminæ result from the mass of the fibres passing in the curve of the cornea, but none of them reaching throughout the whole extent of it, and not being continued in their whole course in precisely the same line; so that some fibres are constantly terminating, and passing into the layer above or below; whilst others are as constantly arising; that while the general mass pursues a horizontal course,* from one margin of the cornea to the other, and the fibres for the most part of their length lie side to side in parallel layers or nearly so, their terminations pass into other layers, and thus connect them together; so that the number of lamellæ which can be shown will entirely depend upon the delicate manipulation employed in separating them, until the individual fibre is obtained. This mode of connexion satisfactorily explains why the cornea should be stronger and more resistant in the direction of the lamellæ than between them. The layers are more intermixed, and not so distinct towards the outer convex surface of the cornea, as towards the concave inner surface, where the lamellæ are far more distinct from each other. Towards the outer surface may not unfrequently be seen fibres passing obliquely and crossing each other from the conjunctival tissue into the true corneal; these, I believe, are the elastic fibres of the basement membrane, and are really those which Mr. Bowman has figured as being part of his anterior elastic lamina, which I do not think has any existence as a separate structure in a normal state of things. The interstices of these fibrous elements are, as probably is the case with those in every other tissue, filled with liquid particles; but probably these interstices are so minute, that the fluid may rather be regarded as forming an integral part of the tissue, than as fluid mechanically contained in cells. Though by pressure on the eye drops of fluid may be made to exude from the cornea, this rather shows the cornea to be porous, and to allow the aqueous humor to exude through it, than proves it to contain fluid; for if a portion of the cornea be separated and subjected to pressure, it will be found difficult, if not impossible, to obtain any fluid from it.

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* In using the words horizontal and vertical, it must be borne in mind, that they have reference to the surface of the cornea when laid flat for examination, and not in the usual position of the eye of the living man.

The best method of examining the lamellar structure of the cornea is, I think, to remove the anterior part of the sclerotic with the cornea, from the eye of a bullock just killed, place it in water in a warm room, until the cornea begins to swell, then to place as thin a vertical section of both coats as can be made, upon a slide, tease it gently out so as not to tear the corneal layers, moisten it with acetic acid or liq: potassæ, and gently, but firmly, press down the cover, and observe with an ½ or ¼ inch object-glass, when the condensed fibres of the narrow sclerotic will be seen expanding into the delicate nucleated fibres of the thick lamellar cornea. See plate 1.

Bowman has described a complicated and numerous series of tubes in the cornea, which he has figured injected with mercury and vermilion; these he thinks constitute a part of its normal structure, being, as he supposes, for the purpose of conveying nutriment to the tissue, and thus forming a substitute for blood-vessels. Other anatomists have failed to observe them; I have not been more successful, nor do I believe in the existence of any such special arrangement of tubes. It would be very difficult to point out in what respect such nutritious tubes should possess advantage over blood-vessels as minute as these canals are described to be. I should rather suppose the tubular disposition of the injected substances resulted from these finding their way among the fibrous lamellæ, and thus indicating the form and direction of them, than from entering and distending any peculiar tubular structure. Bowman has also described a fourth tissue in the cornea in the form of an anterior elastic lamina, between the conjunctival elements and the true lamellar cornea, thicker than the posterior elastic lamina, closely attached to the true cornea, and intimately connected with it by numerous elastic fibres, which it sends obliquely in various directions into it; the supposed use of the structure being to maintain the proper course of the anterior corneal surface. I have looked most carefully for this layer, in man and many animals, with the assistance of such reagents as at once demonstrate the presence of the posterior elastic lamina, without having satisfied myself of its existence, which therefore I do not believe in as one of the normal tissues. In some cases I have observed the basement conjunctival element thicker than in others, and sending what I have thought its elastic elements into the true corneal tissue; and particularly so in human staphylomatous corneæ, resulting from purulent ophthalmia, which I have removed in consequence of their projection preventing closure of the eye-lids. Hence I am inclined to think if such elastic layer has been found in individual cases it is abnormal. This view is materially strengthened by an examination of the eyes of fish (the cod or haddock for instance,) where the cornea is very large and has its separate portions very distinct from each other. The skin is closely attached to the margin of the orbit, then to the edge of the sclerotic, and becoming transparent, though carrying with it for some distance over the cornea some of the beautiful stellate cutaneous pigment cells, is very loosely connected with the true lamellar cornea by means of delicate lax cellular tissue containing a large quantity of fluid. This is true thick basement membrane, being in fact skin a little modified, and rendered transparent.* Next is then the true cornea, continuous with the fibrous portion of the sclerotic coat, the cartilaginous cells abruptly terminating at its edge. There is then beneath this, and by no means firmly connected with it, the elastic structureless layer, as in mammalia; but there is not the least appearance of any similar elastic layer on the anterior surface of the lamellæ. It may be said, that as the cornea of fish is nearly without curve, and the use of the anterior layer being for the purpose of maintaining a due curvature, we ought not *à priori* to expect its presence in them; but this argument would prove too much, for it would equally apply to the existence of the posterior as to the anterior elastic lamina, and this is found well developed.

The third portion of the cornea is a very important one, which has long been known, under the name of elastic lamina; cartilaginous layer; membrane of Descemet or Demours; membrane of the aqueous chamber; it can be seen by the naked eye as a distinct tissue. It is easily separated from the cornea to which it is closely, but by no means firmly connected; it is unaffected by the reagents which cause the lamellar cornea to become opaque. It resists maceration and putrefaction for a long time: boiling water, strong spirit, bichloride of mercury, acids, or alkalies, do not affect it. It is perfectly transparent, quite structureless, easily torn, yet hard, and dense to cut, yielding a grating sound to the knife or scissors; and so elastic that when detached from the cornea it is almost impossible to retain it in a single smooth layer, for instantly it curls up, and always in a direction contrary to the curve in which it is laid down; the anterior convex surface curling forwards, and inwards, so that it appears to be constantly exercising a force upon the cornea like an elastic web.

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* In the cod there is very little indication of epithelial cells either upon the eye or the general cutaneous surface.

It is coextensive with the cornea. In animals with elliptical cornea it is even larger than the lamellar cornea; its edge has a complicated arrangement as was first clearly described by Bowman. It is covered with a single layer of epithelial cells, which are polygonal in shape, apparently from pressure against each other. Plate 1. They are smaller than the conjunctival epithelial cells, and their nuclei are not so distinct; they are also more easily detached, and lost, consequently require more careful looking for at an earlier period after death. They are easily traced as far as the border of the cornea, where Bowman describes them as terminating, while Kolliker declares they are continuous as a perfect epithelium upon the anterior surface of the iris. Though I have sometimes been doubtful of the existence of these cells upon the anterior surface of the iris, even in large animals I have so generally altogether failed in detecting any vestige of them that I should have inclined to agree with Bowman and Hassell in thinking they do not pass on to the anterior surface of the iris, were it not that in one instance of the eye of a sheep just killed I feel certain cells precisely similar to those on the posterior surface of the cornea also formed a thin irregular layer on the anterior surface of the iris, from which they were easily detached: hence I regard their existence or non-existence as still not positively determined. At the edge of the cornea the elastic layer has a complicated termination, dividing into three unequal parts. Fig. 84, page 176. The outer portion passes on the outer boundary of the canal of Schlemm, or circular venous sinus, where it becomes lost in the structure of the sclerotic, with the elastic fibres of which, indeed, it appears to be continuous. The middle portion passes on the inner side of the canal of Schlemm, which thus appears to be in great part formed, it is lost in the ciliary ligament or muscle; while the third, and principal part, is thrown into folds more or less distinct in different animals, and even in individuals of the same species, so as in some to form distinct columns under which a fine Anel's probe may be passed, while in others it is more like an irregular expanded membrane, to be reflected upon the anterior surface of the iris, constituting the pillars of the iris of Bowman, and the ligamentum iridis pectinatum of Huck; here they become modified and lost, but I think I have traced them in the sheep as a delicate expanded layer nearly as far as the pupil and apparently constituting a part of the radiating portion of iris (plate 1). To this subject I shall presently have again to refer. The precise nature of this elastic layer has not been clearly defined, the tendency is doubtless to regard it as made up of the yellow fibrous tissue, with which it appears to be continuous in the sclerotic, though if it were so it is difficult to conceive of its being entirely structureless, and it certainly possesses many properties which ally it closely with cartilage. The effect of reagents upon the two is not dissimilar, the physical properties are alike, and when the inner surface of the elastic layer of the fresh eye of some animals—the sheep for instance,—is viewed under the $\frac{1}{4}$ object glass so strong a resemblance is sometimes presented to cartilage cells as to deceive the eye and make it very difficult to distinguish between the two, which its epithelial cells may perhaps account for.

That the cornea really is supplied with nerves the pain which is felt when it is ulcerated or inflamed is sufficient evidence; but it is extremely difficult to demonstrate their presence, for though Kolliker describes them as from twenty-four to thirty-six in number, readily to be seen in man, and mentions Schlemm and Rahm, as also having described them, many equally good observers, amongst others Bowman, have failed to satisfy themselves of the existence of nerves. As a demonstrated fact, indeed, it must be most difficult, if not impossible, in many tissues to show their presence under the microscope, inasmuch as in their minute ramifications they lose their characteristic tubular character, and thus present no means for recognition from other structures in which they are imbedded—so that while the presence of nerves may be asserted as a fact, which no surgeon for a moment can possibly doubt, it is at present one rather resting upon inference than demonstration. In the young rook I have thought I have been able to trace several filaments passing into the inner surface of the cornea from the long ciliary nerves. In these creatures these nerves are large and pass close up to the attachment of the iris to the margin of the cornea, where they divide into numerous branches, forming a very free inosculation with each other; many of the branches certainly pass on to the iris, and I believe some to the cornea, but in consequence of their losing their tubular character it is very difficult satisfactorily to ascertain their ultimate distribution.

So also with regard to absorbents,—ulceration, cicatrization, effusion, suppuration, and absorption readily take place in the cornea, so that if absorbents do not exist similar functions to what are regarded as peculiarly belonging to them must be performed in other ways,—yet no absorbents have been detected in the cornea by most observers; for though Kolliker gives a figure of what he considers to be absorbent vessels in the cornea of a young cat, he appears to have been unable in any other instance to perceive a similar structure, and therefore probably is mistaken in the particular instance, and I cannot but think Arnold who figures (*plate* 2 *figs.* 7 *&* 10 *Icones Sensuum*) numerous conjunctival and corneal absorbents as filled with mercury has been deceived.

The cornea is now generally regarded as extra vascular, and certainly in the adult human cornea no blood-vessels have been detected; it is therefore not impossible that the deeper parts of it are nourished by imbibition of the liquor sanguinis, which may perhaps form the more liquid portions of the fibrous lamellæ: yet as it is certain that in the fœtal state vessels conveying red blood do freely permeate the fibrous portion of the cornea from the sclerotic, and also that vessels from the sclerotic conjunctiva do form a free net work over the whole corneal conjunctiva, so in the adult it is by no means improbable, that though in the normal condition impermeable to red blood, yet that vessels do exist; if not, then it is obvious, that under slight irritation they are most quickly created and removed, while in long continued irritation they form a thick layer of large and congested vessels so dense as to render the cornea impervious to light and thus to destroy the sight. The presence of nutrient vessels in the conjunctival basement membrane would more satisfactorily account for the nutrition of the cornea than imbibition from the sclerotic margin.

As has been mentioned in good injections the vessels are seen to form plexiform crescentic loops parallel with the margin of the cornea (pl: 1). One of the figs. is a sketch taken from the cornea of a young cat, which was accidentally suffocated in a moderately hot oven; the vessels of the eyes were greatly injected. In this animal, though the larger vessels ran parallel with the edge of the cornea, several of the inosculating loops were rather in the opposite course, and many of the branches could not be detected as forming loops, but rather appeared to pass forwards, and be lost in the cornea. Arnold in his plate 2 figure 6 gives a figure of the conjunctival vessels passing freely and continuously over the cornea.

CHOROID.

The choroid coat is the dark tissue interposed between the delicate sentient retina and the hard dense sclerotic. It is coextensive with the latter. It may be described as commencing at the entrance of the optic nerve, by a round aperture with a distinct edge, in close apposition with the nerve, but not organically connected to it, and passing forwards as far as the junction of the sclerotic and cornea, where as choroid proper it terminates; but it is there in connexion and continuation with three other important structures, which formerly were regarded as parts of it, and now, indeed, though requiring a separate and minute description can only be correctly understood by keeping this intimate connexion constantly in mind. They are the ciliary circle or muscle, the ciliary body, and the iris. The choroid is firmly attached to the sclerotic for a short distance round the optic nerve, and also at the points of entrance and exit of the blood-vessels and nerves; at other places, though in close contact, the two are only loosely connected by very fine connective tissue, until the insertion of the choroid with the ciliary muscle, at the junction of the sclerotic and cornea; where the union is so close that in the recent state it is impossible to detach them without the rupture of some fibres, indeed some particles of the colouring pigment of the choroid are carried into the structure of the sclerotic, as a section of this part under the microscope shows. Throughout its entire extent the choroid is in contact with the sclerotic, until about the one-eighth of an inch from its anterior termination, where is found the ciliary muscle; in other places there is merely interposed the ciliary nerves and the long ciliary blood vessels. The delicate tissue which connects the two coats was by the older anatomists thought to be derived from the pia mater, or arachnoid, passing out of the cranium with the optic nerve, and has been described as a distinct tissue under the names of *tunica anachnoidea*, and *lamina fusca*. Arnold has recently described and figured it, as consisting of two layers, an internal, covering the choroid, and an external, the sclerotic, being reflected behind on the optic nerve, and anteriorly at the attachment of the two coats, thus constituting a closed sac, with a contained fluid, allied to the serous membranes. I have never been able to see anything to justify such a description, nor do I think it is deserving of any distinct appellation, being only a very thin and delicate layer of such tissue as is so generally found connecting contiguous parts all over the body, and moistened as all such tissue is with a little serous fluid in its meshes.

The choroid is essentially a vascular membrane, being made up of blood vessels, colouring matter, and some wavy fibrous tissue, which is a modified white fibrous tissue. In man it is thin and easily torn, but in the larger animals, especially the ruminants and pachydermata, it is much thicker, and may be in its posterior portion divided into two or more layers; this, however, is merely an arbitrary and artificial separation, there is no natural arrangement of it into two distinct coats, as was supposed by Ruysch, who first pointed out the wonderful vascularity of the tissue, resulting, as he described, from the distribution of the arteries on the inner surface, and the veins on the outer, so that the two can be separated into distinct layers: when so separated the inner has since been called the *tunica Ruyschiana.* The larger vessels are on the outer surface, the inner is in a great degree made up of a most wonderful net work of capillary vessels, which are so numerous that the interstices are much less than the vessels, and which, in a successful injection of vermilion size, give to the entire membrane after the colouring granules have been washed off, and it is looked at by the naked eye, or even a magnifying glass, a brilliant uniform crimson hue; but when examined in the microscope with an inch object glass, the real structure is developed as seen in plate 4. Not unfrequently in some animals there is an approximation to an irregular stellate arrangement as is seen in the pig, ox, and lamb, figs. 5, 6, and 7, plate 4. It is this layer of capillaries that Ruysch injected, and was able by a little manipulation to detach from the larger and exterior blood-vessels in the choroid of the calf, and not the arteries alone from the veins, as he and many anatomists since have thought. The network is closer and the vessels more numerous towards the posterior part of the choroid than towards the anterior. The arteries are principally derived from the short posterior ciliary; which pierce the sclerotic, as already shown, at a little distance from the optic nerve, and pass immediately into the choroid. They are much smaller and far more numerous than the veins, they lie more in the tissue of the coat than do the veins, and by their numerous branches form no small part of its substance. Anteriorly they are continued into the ciliary processes; and some of them pass through the ciliary muscle, where they assist in supplying the iris, and inosculate with the long and anterior ciliary arteries. Plates 3 and 4.

The choroidal veins form a beautiful object, indeed, they offer, perhaps, the most curious arrangement of any vessels in the body. They do not accompany the arteries. They are situated towards the exterior surface of the membrane, and from their peculiar course they have been denominated the *vasa vorticosa.* They present a close resemblance to the trunk and branches of the weeping-willow tree when not in leaf. There are usually four, sometimes five, of these venous trunks in each eye, and though the branches of the two adjoining inosculate freely with each other, still the groups are tolerably distinct; some of the vessels commence in the back of the eye, others at less and varying distances, and following the curve of the globe with a gentle sweep, but in tolerably straight lines, they run forwards, many of them as far as the ciliary muscle, where they turn with a sharp curve along it, and uniting form a nearly straight horizontal vessel, of considerable size along its posterior edge, which, receiving in its course the blood from the ciliary processes and the iris, curves backwards, meets with a corresponding vessel from the opposite direction, and these again being joined by other vessels, the result of the union of three or four smaller veins, the whole form a single trunk, which opens obliquely through the sclerotic coat, somewhat anterior to the transverse axis of the eye, and with the other vasa vorticosa assists in forming the ophthalmic vein. Thus the principal vein forms the trunk, and the larger and smaller veins, the large and smaller branches of the tree. By such an arrangement of the arteries and veins the free and uninterrupted supply of blood will be secured, its course rendered slower, uniform and equable, and probably all pulsation prevented. These veins are often found injected after death, and may be seen by simply removing the whole of the sclerotic coat and placing the eye in water; fig. 2, plate 3, shows the general arrangement of them; but the best way of seeing them is to cut out a third of the choroid coat of the sheep, ox, or horse, with the ciliary muscle, ciliary processes, and iris, gently wash away as much of the colouring matter as possible, and very carefully spread the whole out upon a thin watch-glass, the curved surface of which allows the membrane to lie smooth; when dry and viewed with an inch lens, not only will the vasa vorticosa be beautifully seen, but also the continuity of the ciliary muscle, ciliary body and processes, and iris with the choroid.

The choroid coat does not appear to be very freely supplied with nerves though it certainly has some, those it does receive are filaments from the ciliary nerves, which run in shallow grooves between it and the sclerotic, they however are destined for the ciliary muscle and iris rather than the choroid. So far as operations, wounds of it, and alteration in its texture, enable us to judge it does not appear to be very sensitive. The choroid is universally pervaded with the pigmentum nigrum, and is described as being "of a deep brown colour approaching to black." In most mammalia, birds, and many reptiles this is the case; in some the colour is quite black; but it certainly is not so in man, and I cannot but think the general impression of its blackness arises from the almost universal, and, for the most part unavoidable, practice of dissecting the eyes of sheep and other animals instead of the human organ. In man the pigment is not only less abundant, but it is much less intense in colour than in many animals, seldom being in the adult of more than a burnt umber brown, and often not more than chocolate or mahogany red. It is often in the old deeper in patches and along the blood-vessels than equally deposited. It usually is sufficient in quantity to render the choroid comparatively impervious to light, but I have dissected several human eyes, where there has been so little of the pigment, that the inverted figure of an object held between the light and the cornea, could be perceived upon the sclerotic in the unopened eye; which can rarely be done in an animal, unless it be an albino.* The pigment covering the ciliary processes and back of the iris is always, so far as I have seen, darker and more dense than upon the choroid, so that these parts are always impervious to light, and thus none can enter the living eye without passing through the crystalline lens. In children the pigment is usually darker and more abundant than in old persons,—it is more so in those with dark hair and skin than in light individuals and races, and more so in the inhabitants of the torrid and frigid districts of the world, than in those who live in mild climates; no doubt from the necessity of such persons having the retina protected from the intense light of the sun and the long continued and brilliant reflection of the snow. The pigment pervades the whole tissue of the choroid, it is not unfrequently described as being thicker on the external surface of the coat than on the internal; but this I do not think to be the case. In man the coat is so thin, that unless the pigment were merely spread upon the surface, there is hardly thickness of tissue to permit of one part being much more thickly imbued than another, and in animals it appears to rather result from the arrangement of the particles, than from any other cause. In the structure of the choroid and towards its external surface the pigment is deposited among the vessels and fibres which form the tissue and which are deeply imbued with it, their natural pale grey colour only appearing after free ablution, and as the choroid is connected to the sclerotic by cellular tissue, this also carries some of the pigment in its meshes, and hence the sclerotic itself is always stained of a dark colour.

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* This I believe to be true of most animals, but it is not universal. In the pig for instance, the image of the flame of a taper held before the unopened eye in a room otherwise dark may be perceived upon the opposite point of the sclerotic with considerable distinctness, though not at all equal to that seen in some human eyes.

The pigment is described as consisting of two distinct forms of cells: on the inner surface of the choroid of true hexagonal cells, and in the tissue and on the posterior surface of stellate cells. That under the microscope both these forms are readily and distinctly to be recognised in man and most animals is certain, but that they are true cells I am not inclined to admit.

When the internal pigmentary surface has been washed or scratched off, and a portion of the choroid coat is then teazed out, a large number of irregular stellate dark bodies are seen more or less intimately connected together, and that in proportion to the amount of teazing out the portion has been subjected to; if considerable they may be completely detached, appearing as a nodulated centre, with irregular sized and shaped arms; if less, then the centres are more or less connected together by the arms; and in the same proportion as the separation, so does the number of detached minute pigment cells increase (plate 2). I believe these stellate forms to be portions of vessels and fibres from the tissue of the coat, and to which the minute pigment cells adhere by a mucus, which appears to accompany them, and not to be really stellate pigment cells. There is not unfrequently in them some of the clear granular bodies below mentioned, as found in the hexagonal forms.

On the internal surface the pigment is arranged in a distinct layer, which lies to the inner side of the network of capillaries, and is in contact with the retina. Mr. W. Jones was the first to point out the beautiful hexagonal form of this pigmentary layer, as consisting "of very minute flat bodies of a hexagonal form, joined together at their edges, about the $\frac{1}{1000}$ of an inch in diameter, consisting of a central transparent nucleus surrounded by an envelope of colouring matter, which is most accumulated at their edges." Subsequent writers and observers have described these bodies as being true cells enclosing the pigment. It has been called the choroidal epithelium, a name which its shape and position probably suggested.* The hexagonal arrangement of these bodies may readily be seen in almost all, if not all, mammalia. I have traced them from man, in whom, though evident enough, they are not so distinct as in creatures possessing a stronger and darker choroid, through the various orders of mammalia down to the mole, whose eye is so little developed, as to have formerly been thought not to be present, and even in some reptiles, as the alligator, they are distinct enough (plate 2). In birds, instead of an hexagonal, there is a pyriform arrangement, in which the central transparent nucleus is not so apparent (plate 2, figs. 8 and 9). In some rodents, the rabbit and rat for instance, the arrangement appears intermediate between the true hexagonal mammalian form, and the pyriform of birds; but in which the nucleus is very distinct. Of all animals which I have seen the horse presents the most distinct appearance, (plate 4, fig. 6), where the inner surface of the choroid strongly resembles, and is as beautiful, as the cornea of a hard skinned insect. These bodies I believe not to be true cells, having a capsule. They appear to me to consist of clear granular, nearly globular nuclei, about which the pigmentary matter is collected, and held by its mucus; † and that the hexagonal form is rather the result of lateral pressure against each other, than their primary shape, as when gently separated they may be seen to lose the hexagonal and acquire the globular form; and we find that nearly all yielding globules when in close layers assume more or less of the hexagonal form from a simple physical law. If, indeed, my idea of a layer of globular granules be correct, and the pigmentary matter be deposited between them, then the dark dense black hexagonal margins and clear circular nuclei is a necessary arrangement of the whole layer, more or less perfect according to the pressure. The transparent nuclei appear to be spread over the whole surface of the choroid even in animals where the colouring matter is not, for where a tapetum is found, the colourless globules are spread over it as over other parts (plate 2, fig. 7). By slight decomposition, or by washing, the colouring matter may be detached from the central granular portions when these are seen in size and general appearance very closely to resemble the granular bodies so plentifully found in the retina; and they appear to me to be very closely and organically connected with the retina. I think they are nucleated, and contain granules, and not fluid. In man and mammalia the retina is not stained with the colouring of the choroid; to account for which, contrasting so strongly with the sclerotic, it has been thought there is interposed a membrane, first described by Jacob, and hence called the membrane of Jacob, which other anatomists have further described as a double serous membrane. Dalrymple also has given many physiological and pathological reasons in support of its existence as a sac. There can be no doubt that the part which Dr. Jacob described as a membrane is in reality the outer bacillar layer of the retina, and there is not the least anatomical ground for believing in the existence of anything like a serous sac; the pathological conditions of this part of the eye being more satisfactorily accounted for by a knowledge of the true structure of the inner surface of the choroid. In birds, I have mentioned that the clear central nuclei are not so apparent as in mammalia, but in them there is a very beautiful arrangement of coloured globules on the outer ends of the rods of the retina, where they are in contact with the choroid, and it possibly may be that these are the analogues of the globules in mammalia.

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* I am inclined to think some of its pathological changes also support this idea.

† Indeed in some animals I have at times doubted whether the appearance of clear nuclei did not rather arise from the light passing though an aperture than from a true nucleus.

Over the back of the iris, and in the folds of the ciliary processes, the pigment is continued, where it always forms a denser, more impervious layer than in any other part of the eye. In those eyes where but little is found in other situations some always is found here; even in the red eye of the white rabbit, where the absence of it in the choroid permits the blood in the vessels of this coat to be seen through the pupil, the back of the iris and the ciliary processes, almost always have some little pigment upon them. In these situations there are fewer of the clear nuclei and more of the pigment and its mucus, and the hexagonal arrangement is not nearly so perfect, probably from the want of that close aggregation and pressure which they have in the choroid coat.

In all mammalia, and birds and in many if not all reptiles,* I believe the true pigment is essentially the same as in man. It consists of exceedingly minute cells of nearly uniform size, and, apparently, of the same, or nearly the same, size in all animals, held together and attached to neighbouring fibres by mucus. These cells are seen in myriads, moving most actively about in any fluid; they appear singly to repel each other, like two bodies in a similar electric condition, for when two are within a certain range of each other there is evidently a repellant action, but when in a mass such action is not observed. When in a very thin layer they are by transmitted light of a light red brown colour, but by reflected and also by transmitted when in considerable number they appear a dense black. They form the most perfect absorbers of light of any substance in nature that I know of, for a very thin layer destroys a large beam of light, hence their use in the eye. The intensity of the blackness appears to depend entirely upon the number of these minute cells aggregated together; for, so far as I can judge the colour of the individual cells appears to be pretty uniform and similar in all creatures. They seem to have a tendency to arrange themselves in fibres, or the fibres of which the pigmentary masses consist, break up into them; but as they appear to be true cells, filled with fluid they must rather be taken for the primary element (plate 2)

I believe them to be identical with the pigment cells of the rete mucosum, and the colouring matter in melanosis. They are more abundant in the eye of those individuals and races where there is the darkest skin and hair, and to my sight the appearance under the microscope of the cutaneous pigment and that of the choroid is the same. Such correspondence also appears to me to exist in fish, where the external face of the choroid and the anterior surface of the iris are silvery and glistening from minute iridescent particles; which, except in reflecting completely the light, have identical functions with the dark cells of mammalia. The glistening rete mucosum of the belly and gills in the salmon and the cod are essentially, under the microscope, the same as the spicular crystalline-like bodies from the anterior surface of the iris, and the outer of the choroid; both appear in transmitted light as deep black, by reflected they are beautiful silvery spiculæ, and are held together by mucus, vessels, and connective fibres. Plate 2. The pigment cells are very permanent, they are unaffected by water, acetic acid, ammonia, and liq. potassæ: they contain a large quantity of iron; Lehmann says that he has found in the pigment from the choroid coat of the eye 0·254$\frac{0}{0}$ of iron.* In animals who exhale any particular odour I have thought the eye, more particularly its colouring matter, to possess this in a concentrated degree: in many birds, the rook for example, it is very strong. The use of this pigment is obviously a physical one; that upon the iris and ciliary processes of preventing any light entering the eye there, except through the crystalline lens; and that upon the choroid, of destroying the light which has inpinged upon the retina. As the pigment is secreted from the blood, it probably explains why all the tissues, the choroid, ciliary processes, iris, and in birds the pectin, where it is found, are so vascular. So far as we can judge of their functions, there is no other reason why these tissues should be so. The large amount of iron which it contains demands for its elimination a large quantity of blood.

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* I have examined it in the frog, toad, water newt, alligator, turtle, and chamelion.

This account of the arrangement of the pigment affords, I think, a satisfactory anatomical explanation of an abnormal condition which has hitherto not been understood—*muscæ volitantes;* if any one who has himself been subject to these motes, or has got patients who are so, to draw figures of what they complain of, will examine, as I have described, a portion of choroid coat teazed out, he cannot fail to be struck with the perfect resemblance of the two—the nodulated masses with connecting and stellate fibres, and the muscæ volitantes. It also explains why these *muscæ* may be temporary or permanent, trifling and functional, or very serious and organic. If the stellate arrangement results, as I believe it does, from the aggregation and attachment of the minute true pigment cells to the vessels, the least variation in this connection or the condition of the vessels may at once cause an irregular arrangement of the pigment cells and impress the retina (for we must bear in mind that all images upon it are microscopic). This impression may appear and disappear with the varying conditions of the vessels arising from disordered stomach or cerebral circulation, and be cured, as we know it constantly to be, by whatever corrects their condition; or the *muscæ* may result from different organic changes in the choroid coat, which are incapable of being removed, and may indicate patches of effusion or other structural lesions. In point of fact we now know the important bearing which these dark specks have in our diagnosis of that important class of choroidal and retinal diseases which have been so generally confounded under the name of amaurosis and glaucoma. It also explains why these *muscæ* may be constant in form in one case, and constantly changing in another; in the latter a different loop of capillaries may be congested or contracted, or a morsel of fibrine may be deposited or absorbed; in the former the deposit may be organised, or the capillary permanently altered. See plate 2.

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* Physiological Chemistry, vol. i. p. 310.

CILIARY CIRCLE OR MUSCLE.

If the sclerotic be divided about the one third of an inch from the cornea, and this portion with the cornea be carefully detached we find a whitish grey circle about the four-thirtieth of an inch broad, extending from the junction of the sclerotic and cornea backwards upon the choroid. It is always a circular belt even in those animals, whose cornea is elliptical, as its attachment is to the junction of the inner surface of the cornea with the sclerotic and iris, *which is always circular*. Plate 3. This substance has received various names as ciliary circle or ring, ciliary ligament, ciliary ganglion, and ciliary muscle, according to the notions which have been entertained of its structure and functions. These have been most obscure and contradictory; some persons have believed it to be a tendon and ligamentous; others a congeries of mucous follicles; others again, observing how freely the ciliary nerves enter and subdivide in its structure, have regarded it as a true ganglion of the sympathetic system, and consequently a part of great importance; while many anatomists even of late date and no mean pretensions, as the late Mr.

Dalrymple, have described it as no more than connective tissue, merely uniting and strengthening other and more important parts; as the ciliary processes and iris, with the corneal junction. Mr. Bowman was I believe the first, at least in this country, to describe it as formed of unstriated muscular fibres, a view which is now generally adopted, and hence it is now commonly known as the *ciliary muscle.* This part is relatively larger and more distinct in man than in many animals whose eyes are much larger,—the horse for instance. It is thicker anteriorly than posteriorly where it terminates at a line corresponding with the ora serrata of the retina, and the commencement of the ciliary processes; with these it is co-extensive, and, indeed, when the colouring matter is well washed away, it appears very like a portion of the ciliary body extending to be most closely connected with the line of junction of the sclerotic and the cornea, and then to be continued on into the iris, upon the anterior surface of which some of its fibres may be distinctly traced.*

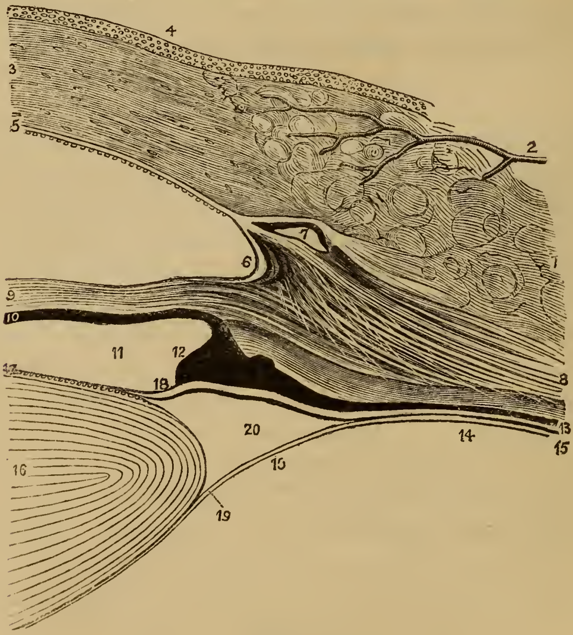

Fig. 84.

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* Fig. 84 is an enlarged section of this important part of the eye, and will illustrate the parts described in the present, the preceding, and some subse-

It may be described as arising from the circular sinus of Schlemm, to which it is very intimately connected, and thus not only assists in the attachment of the iris to this point, but is the bond of union between it and the ciliary processes. To the naked eye it is a soft granular-looking layer, into which the ciliary nerves and long ciliary arteries, with many of the anterior ciliary may be traced, it is consequently a highly organized body. Bowman states that its size is in accordance with that of the ciliary nerves, and hence infers its proportional activity of function in such creatures. I cannot say that I have observed such correspondence in volume; and it appears to me very doubtful if the older opinion of the nerves merely passing through it to the iris is not in some degree, though not its full extent, correct. That the size of the ciliary nerves corresponds rather with the activity of the iris, to which they all ultimately pass, than with the size of the ciliary muscle is I think more in accordance with my observations. They will be more particularly referred to afterwards.

When a thin section is teazed out, it is seen to consist of fibres passing from before to behind in layers superimposed upon each other, which present all the characters of unstriped muscle. In

quent sections. It is made from sections of the eyes of oxen in a fresh condition, also from others spread out, dried, and then moistened with liq: potassæ or acetic acid, by which some portions are better seen. It is to be regarded as a descriptive plan rather than one drawn to a scale with precise accuracy of the absolute dimensions of the various parts, though in this respect it is not far wrong. While it presents a general resemblance to those of Bowman and Kölliker, it is modified in several particulars, in accordance with what appears to me to be the condition of the parts on examination of them.

1, sclerotic; 2, conjunctival vessels, (shown somewhat too large and as penetrating the sclerotic too much;) 3, fibrous cornea; 4, epithelial layer of cornea; 5, its elastic layer covered with epithelial cells, and which separates into three portions, one of which passes on to the anterior surface of iris, forming as it does so, 6, the pillars of the iris; a second which passes into the sclerotic on the outer side of the foramen of Schlemm 7,—the wall of which it forms; and a third which passes into 8, the ciliary muscle; 9, the iris; 10, its uveal surface; 11, the posterior aqueous chamber; 12, the ciliary processes; 13, the retina, terminating at 14, the ora serrata; 15 15, the hyaloid membrane passing behind the crystalline lens 16; 17, anterior capsule of lens with its interior epithelium; 18, the suspensory ligament of the lens, a thick portion passing upon the anterior surface of the lens, a much thinner 19, upon the posterior surface, and leaving between them a space, 20—the canal of Petit.

birds, indeed, Bowman declares it to be, like the iris, of the striped kind. I cannot say that I have observed the striæ in them, but in all creatures its structure appears very similar, and to consist of fibrillæ containing nuclei, which are rendered more distinct by the addition of acetic acid, while the fibres are made less distinct. See plate 2. Porterfield long ago conjectured it to be muscular and to act upon the lens, a view Bowman appears to adopt; supposing that when the fibres contract, by their action upon the choroid and the ciliary processes the vitreous humour is compressed laterally, and the lens drawn forward, the eye thus being adapted for near vision.

That the part performs some most important function its position, connections, and organization prove beyond any doubt; and its resemblance or identity with unstriped muscle would lead to the adoption of the idea of its contractile property, yet I cannot see how it can have the action attributed to it. Its fixed point is the junction of the sclerotic and cornea, towards which it consequently would draw the more moveable points of attachment; and as from this it proceeds outwards and backwards upon the choroid, it would tend to pull this forwards and inwards; but the length of fibre is so short as to render it scarcely probable that it can counterbalance the loose elastic tissue of the choroid and pull the whole of this coat so far forwards as to act upon its contained vitreous humor; which is again supposed to carry forwards the lens imbedded in it. Then again it is supposed to act directly upon the lens through the intervention of the ciliary processes, and thus by pulling them outwards, to drag the lens by their attachment round its margin forwards. This cannot take place. The ciliary processes are not attached directly to either the lens or the hyaloid membrane of the vitreous humor, but, as will hereafter be described, to a strong membrane, the suspensory ligament of the lens, which is interposed between the ciliary processes and the hyaloid membrane, and passing over the anterior surface of the lens preserves it *in situ*. Now, though certainly the ciliary muscle in contracting would draw forwards and outwards the ciliary processes, yet as the anterior surface of the lens projects forwards anterior to the processes, it would by this action be compressed backwards, as the suspensory ligament cannot be drawn outwards without pressing the lens more into the vitreous humor, and thus, whatever change of position be effected, would I think be in the opposite direction to that which Bowman imagines. That it has some important functions to perform cannot be doubted, probably in connexion with overcoming the aberration of parallax, but in what precise manner it is very difficult at present to say. I rather incline to associate it with the actions of the iris, with which it is so intimately connected as to constitute an almost continuous, if not identity of, structure, than with alterations in the position of the lens. It more agrees with the iris in development than with the ciliary processes; its organization is also similar, its vessels and nerves are alike, while the ciliary processes do not appear a likely structure to propagate any slight motion from it to the lens, which would be lost in them.

CILIARY BODY AND PROCESSES.

If the eye be divided transversely at not less than the third of an inch behind the cornea, and the anterior part be laid upon the cornea, there will be seen, in looking into it in a good light, a beautiful radiated disk surrounding the crystalline lens, something as the petals of the sun-flower are arranged round its central seed-bearing part. Plate 3. To this part almost as many names have been given and differences of functions assigned as have been attached to the ciliary muscle, and precisely for the same reason,—the difficulty of ascertaining with certainty its structure, and the corresponding obscurity of function. That which it now commonly bears is ciliary body, it is distinguished into the processes—the *pars plicata;* and the body—the *pars non plicata.*

From the entrance of the optic nerve the retina is spread out upon the vitreous humor interposed between it and the choroid as far forward as the posterior edge of the ciliary muscle, about which point it terminates in a scalloped edge called the *ora serrata,* where the choroid loses its smooth glistening character and is thrown into very slight folds; these increase in breadth, and encroach more and more upon the anterior surface of the vitreous humor until they very nearly reach the margin of the lens, where they lie upon the anterior wall of the canal of Petit; here they terminate in a free edge, which passes outwards to the larger circumference of the iris and the ciliary muscle, with both of which they are continuous. The ciliary processes are of an irregular triangular shape, having an outer somewhat convex edge, which is in connexion, through its entire extent, with the choroid and ciliary muscle; an inner posterior concave edge, which lies in its whole course upon the vitreous humor and suspensory ligament of the lens, and an anterior edge, which is the shortest, forming the base of the triangle, and lies free in the posterior aqueous chamber.

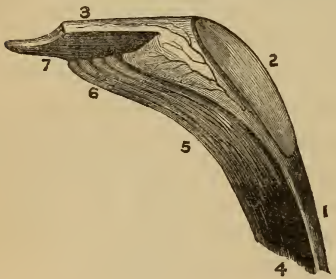

Fig. 85.

The number of these folds is variously given, from sixty to eighty-five, and as consisting alternately of a long and short fold; the number probably differs in different eyes, and according as the small folds are counted or not so will the number be made greater or less. In one eye that I carefully counted the processes of, I found seventy of the large fully developed and as many of the smaller, so that if all were enumerated they would have amounted to one hundred and forty. Soemmerring says—the darker the eye the less is the number of folds in the ciliary body, "Quo fuscior oculus est, eo minor plicularum in corpore ciliari numerus esse solet."* In the fœtus there certainly is a smaller fold contained between each pair of processes, but in the fully developed eye there is not usually any regular alternation of long and short processes, but between many of the larger, small projections are seen, each process however is bifid and consists of two distinct folds united at the base. Plate 3.

They are thickly imbued with pigmentary matter. In their tissue it is deposited upon the fibres and vessels so as to assume the stellate form, but on their entire surface and interstices is a thick layer, as on the inner surface of the choroid, but in which

Fig. 85. 1, choroid; 2, ciliary muscle; 3, iris; 4, commencement of ciliary folds; 5, pars striata of Zinn; 6, five of the ciliary processes; 7, the posterior aqueous chamber.

* Icones Oculi Humani, page 52.

the mucous and minute pigment cells are more abundant, the clear central nuclei less, and the hexagonal arrangement not so perfect. When they are separated from the vitreous humor part of the pigment comes away with the processes, and the remainder adheres closely to the *zone of Zinn:* when the pigment is removed the tissue is found closely to resemble that of the choroid, being made of blood-vessels and a peculiar fibrous tissue, indeed, they really are nothing more than folds of this membrane. When injected the vessels are seen to form beautiful loops, distinctly continuous, with those of the choroid, but in which the capillaries are less numerous and the vessels larger. A part of the vessels in the apices of the processes are terminal loops, others, which are situated towards their bases or the ciliary body, pass on to the iris. Plate 4.

They appear, like the choroid, to contain but few nerves, there is usually more pigment deposited at their bases, and in their interstices, than towards the apices, so that in those human eyes where the pigment is scanty I have seen their points present only a grey colour. In animals the whole body and processes are usually of a dense black colour.

When instead of dividing the eye transversely, only the sclerotic and choroid are cut through, and these coats with the ciliary body and iris are carefully removed, the vitreous humor and lens being left *in situ,* a radiated disk, which is an accurate cast of the ciliary processes, is seen upon the vitreous humor as far as the margin of the lens. This has been sometimes called the ciliary body or processes of the vitreous humor, but is more generally denominated the *zonula Zinni,* after the admirable anatomist who first described its complex character. It consists of a series of foldings in the hyaloid membrane which accurately and closely dovetail with the ciliary processes, but the two are not in contact, as until lately was universally supposed, for there is interposed a thin elastic membrane,—the suspensory ligament of the lens, to be hereafter de-

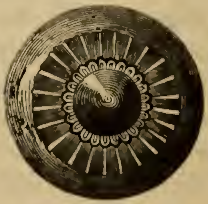

FIG. 86.

Fig. 86 shows the vitreous humor with the lens in situ. Surrounding this is the canal of Petit distended with air, and a larger disk on the outside of it—which is the zone of Zinn.

scribed, and which, contrary to the common opinion, probably prevents any vascular connexion between the two.

It is a question which has been, and still is, warmly debated, whether the ciliary processes advance so far inwards and forwards as to be connected with the edge of the lens, or stop short of this point. The important question as to their power of altering the position or form of the lens, so as to adjust the eye to vision at different distances, being presumed to depend upon there being this connexion or not.

The majority of modern anatomists I think, amongst others Dalrymple and Bowman, agree in stating that there is a clear space between the processes and the lens, in which the vitreous humor assists in forming the boundary of the posterior chamber, consequently that there is no connection. On the other side, Meckel, Monro, and some other excellent anatomists agree with the older observers in supposing that the ciliary processes advance over the margin of the lens, and have an actual attachment to it.

I have examined many eyes most carefully to ascertain this point, in the majority it certainly has appeared, that, though the processes approach very near to the margin of the lens, yet they do not touch it; in other eyes I could not but feel convinced that the processes did overlap the lens, and in these instances, when detached, leave a mark of attachment, and therefore I conclude that the processes do not in every eye advance to precisely the same point. The discovery however of the suspensory ligament of the lens renders the physiological interest much less, and also explains why those, who, because they have not found the mark of attachment upon the capsule, when with the lens it has been removed entire from the eye, could not do so, yet are wrong in thereby inferring that the processes may not overlap it, for the simple reason that the processes are in no case attached, or even in contact with, the lens or its capsule, but with the suspensory ligament. It can therefore make no difference in the action of the ciliary processes, supposing them to possess any motor power, which, to say the least, is extremely doubtful, whether they extend the fiftieth of an inch more or less forward; for as this ligament passes over the front of the lens, any action they could exert would be the same.

If after the lens has been carefully removed by dividing its anterior capsule in the centre, leaving the suspensory ligament undisturbed, this be put upon the stretch with a pair of forceps, I feel certain that in many instances the plicate folds of the ligament, with pigment attached, will be seen passing over the anterior margin of the lens, but much more evidently so in some eyes than in others. The function of the processes is very obscure. It is much easier to declare that most of the hypotheses propounded are false, than to point out a satisfactory one. That they are tendinous, ligamentous, simple cellular tissue, secreting organs to pour out the vitreous or aqueous humors, erectile tissue, and muscular, have all been announced, some of which opinions may be dismissed as altogether incorrect, and not in accordance with known anatomical and physiological facts. For my own part, while not denying that they may exercise some important and unknown power in the correction of the aberration of parallex, I am in the present state of our knowledge more inclined to think their function is a physical one, that by surrounding closely the edge of the lens they act as a diaphragm, and thus, with the iris, prevent any rays of light passing on to the retina which have not traversed the crystalline lens; and that their great vascularity is for the purpose of enabling the large quantity of dense pigment to be secreted, as is the case with the choroid. Whether they exercise any control over the position of the lens is doubtful. An argument for it might be furnished by their position and complicated arrangement, and the fact that in birds, whose eyes appear to undergo the greatest amount of change in viewing near and distant objects, not only are these processes very fully developed but there is a very similar structure—the *marsupium*, approaches to the back part of the lens in such a manner, as that if any contractile property be possessed by them, the two would be the opponents of each other.

IRIS.

The Iris is the floating diaphragm which hangs transversely in the aqueous chamber, and divides it into two unequal parts (fig. 83). It is incomplete, having a circular aperture—the pupil of varying size, nearly in its centre, but slightly to the inner side, so that the iris itself is somewhat narrower towards the nasal than on the temporal side.* The iris may be regarded as a prolongation of the choroid membrane and the ciliary muscle, the vessels of the former being continued into it, and many of the fibres of the latter passing into it. It is attached by its outer margin closely to the point of union of the sclerotic and cornea by means of the continuation of the ciliary muscular fibres into it, and also by fibres from the elastic layer of the cornea, which are here reflected upon it,—the pillars of the iris, and which are more distinct in some animals and individuals than in others, as has already been mentioned; indeed, this spot might not improperly be regarded as the common point from whence these fibres start; one set passing into the ciliary muscle, another into the tissue of the sclerotic, and a third on to the posterior surface of the cornea; so that the iris is intimately attached all round to this point. It is also here continuous with the base of the ciliary processes.

In health it is perfectly plane on its anterior surface, though not unfrequently apparently convex, but this arises from its being seen through the convex cornea, and whenever there is any bulging, which not unfrequently does occur, it is the effect of disease, and is a symptom which should be carefully investigated, as it is always indicative of organic change of some kind. In size the iris corresponds with the cord of the segment of the cornea. Being attached to the sclerotic and corneal junction at a point corresponding with the elastic lamina of the cornea; even in those animals which have the cornea elongated transversely, the outer margin of the iris is circular, and as the inner pupillary margin is elliptical in correspondence with the cornea, it follows that in the vertical direction the iris in them is considerably broader than it is in the transverse. In man and creatures, where the cornea is nearly circular, and there is not much difference in the extent of the posterior and anterior surfaces of the cornea, the iris is circular and nearly of equal breadth. The posterior surface of the iris is, except in the albino, always covered with a thick dense pigment, which is similar in nature to that of the choroid, but the hexagonal arrangement is not so regular, nor are the clear nuclei so numerous, while the minute dark-colouring cells are more so; the quantity of mucus is also greater, so that after immersion for a while in water, the pigment may be raised in patches, which has led to the description of it, by some, as a distinct membrane, though there does not appear sufficient ground for this notion. This is the *uvea*. It often projects somewhat beyond the pupillary edge, especially in the ruminants and pachydermata, where, in the horse for instance, portions not unfrequently wave in the pupil like a lobulated fringe, hence its name. Even in man, when there is an opaque large lens pushing the iris forward, a magnifying-glass will sometimes show an irregular projecting fringe of uvea, clearly not the result of adhesion. Some of the colouring matter is always mingled with the tissue of the iris, and it appears, that from the quantity of this and the manner in which it is arranged, the various colours on the anterior surface of the iris in different persons result. The colour of the anterior surface varies in every individual, but bears some general relation to the colour of the skin and hair. In dark races and individuals, commonly the iris is dark brown; in the fair, light, or red hair, it passes through every shade of hazel and grey to light blue, usually the two irides are alike, but it not unfrequently happens, more especially in the lighter-coloured, that the two do not correspond, or that there are patches of a darker colour; these do not indicate any difference in structure, but merely a larger or less deposit of pigment at the spot. It seems difficult at first sight to believe that the different colours in the iris should not depend upon some real difference in the structure, but such does not appear to be the case. In birds and reptiles where the iris is often of a very brilliant yellow colour, a considerable number of highly refractive cells filled with a clear yellow fluid, very like fat, are found imbedded in the tissue, towards its anterior surface. Soemmerring says, the paler in colour the iris is, the thinner are the coats of the eye-ball, and the darker the colour, by so much are they thicker. "Quo pallidiores colore iris est, eo tenuiores bulbi sunt tunicæ, quo fusca magis illa, eo crassiores hæ.[*] An observation which, Demours says, Maître Jean had also made.

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* Occasionally this inequality is very considerable. I have now under treatment a gentleman, a keen sportsman and a very good shot, for concussion of the eye-ball from the shots of a blundering companion, the inner side of whose iris is in a moderate light just half the width of the outer side. The pupil is so much to the nasal side as to be readily perceptible to the most casual observer. As the pupil in the sound eye, in which vision is perfect, is exactly the same as in the injured one, it must be a natural formation. The iris is as active as in other people.

The anterior surface of the iris is a reflector. It is fibrous and iridescent, decomposing the light which it reflects, and according to the quantity of pigment in its structure, so does it seem darker or lighter; where there is little amongst the fibres, and only the dense layer on its posterior surface, it appears blue or grey; if there be much amongst the fibres, it is dark brown. In all cases when the iris is separated and well washed in water so that all the colouring matter which is not incorporated in its texture is removed, the iridescent appearance is lost, and the fibres are of a uniform light grey colour, and very like the surface of the tapetum in transmitted light; the iridescent appearance of both structures probably depending upon an analogous structural arrangement of fibres and blood-vessels. Both are iridescent only in reflected light. When closely looked at, particularly if a magnifying-glass be used, the anterior surface is seen not to be smooth, but to consist of a great number of projecting fibres, which proceed in radiating lines more or less convoluted and knotted, with frequent inosculations, from the outer attached or larger circumference to near to the inner free pupillary or smaller circumference. These are much more prominent and numerous in some people than in others; in some eyes they quite leave for a space the surface of the iris, and stand out from it. At times they are so conspicuous and fantastical that by the help of a vivid imagination it has been supposed some one or more letters of the alphabet could be made out.[†] Sir E. Home gave some good figures of these fibres, and Dr. Jacob has pointed out their resemblance in appearance to the *chordæ tendineæ* in the ventricles of the heart, and even, from analogy, ventured upon the idea of their muscularity; and, consequently, being the agents for dilating the pupil. There certainly is not the least anatomical ground for this opinion. They are the arteries proceeding from the outer circular vessels, with some fibres from the elastic layer of the cornea. They do not pass quite to the pupillary aperture, but unite a little before reaching it at the inner circular sinus.

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[*] Soemmerring, Icones Oculi Humani, page 52.

[†] Some few years ago, when the Napoleonic furor was being got up in France, some sensation was excited in Paris by the exhibition of a boy, in whose eyes the word Napoleon was stated to be formed. It was nothing more than a large and irregular development of these lines converted into magical letters by the description of the showman and the willing imagination of votaries.

When the pigment is washed from the posterior surface there is to the naked eye an appearance of fibres arranged in two sets, an outer proceeding as numerous fine radii from the outer margin inward and where they terminate there is a ring of fibres surrounding and, in fact, forming the pupillary edge; this arrangement is much more perceptible in the sheep and ox, than in man.

The use of the iris is probably entirely physical. It is the stop or diaphragm of the optical apparatus, excluding all the rays of light which would fall too obliquely upon the lens to be conveyed to a focus upon the retina, and according to its intensity, regulating the quantity of light admitted; an office which it is enabled to discharge by its capability of enlarging or diminishing the pupillary aperture, according as near or distant objects are viewed, and to the vividness of the light. A power so essential to correct vision, and so wonderful, could not fail to excite much interest and desire to ascertain by what means it is effected. The striated appearance and the active motion naturally led to the supposition of the muscularity of the iris, and though a more minute examination, even with the aid of the microscope, entirely failed to demonstrate the existence of muscular fibres, the assistance of arguments founded on physiological analogies and pathological conditions, was called in and urged with much force and ingenuity by more than one anatomist. Indeed it might be said that a few years ago the muscularity of the iris, though certainly not a demonstrated fact, was the commonly accepted opinion in the anatomical schools of England. By no one was this opinion more warmly urged than the late Mr. Dalrymple, some of whose arguments however are by no means very conclusive. On the Continent, following the opinion of Valsalvus, Morgani, Haller, Zinn, Bichât, and other illustrious men, the opinion of the non-muscularity of the iris was probably the one far more generally adopted, and in this country since minute anatomy was more carefully cultivated, relying upon the impossibility of detecting any structure corresponding with ordinary muscular tissue, with the want of voluntary power over the iridal movements, the same opinion was gaining ground; the motions being referred by some to elasticity, by others to erectile tissue, and by others again, to some unknown property peculiar to the iris. The discovery of the widely distributed non-striated muscular fibrillæ has explained the contractile property of more than one tissue, about which the same difference of opinion existed; (as that of vascular tunics), and the now generally recognised fact of the existence of this structure in the ciliary muscle, about which microscopists almost all agree, has naturally led to the searching for it in the iris, where, with nearly as unanimous a consent, it is stated to exist, though as to the particular arrangement of the fibres there is by no means the same agreement; this is not to be wondered at, for the examination is one of very considerable difficulty, in consequence of the great number of blood-vessels, nerves, and elastic fibres in the iris, and the liability there is to confound the minute texture of these different tissues with the isolated fibres of unstriped muscle, which I feel confident some observers have done; indeed, at risk of perhaps exposing myself to the accusation of incompetence from more practised microscopists, I must confess, after the most careful and repeated examination of the iris, to a feeling that is not always possible to distinguish between the ultimate divisions of these structures.

Bowman considers there is a set of radiating fibres much resembling, but not absolutely identical with ordinary unstriped muscle, passing from the outer circumference towards the pupil, but before reaching it that they inosculate in a plexiform manner, and that there are no true circular constrictor fibres; while Hassell, Kölliker, and most other observers state there exist not only radiating fibres, by which the pupil is dilated, but a distinct circular muscle, surrounding the pupil, by which it is contracted. In this statement Mr. Lister* coincides. All agree that in birds and some reptiles the iris contains muscular fibres of the striped variety, which is in accordance with the long known fact, that in birds the motions of the iris appear to be under the influence of volition.

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* Microscopical Journal, vol. i, page 8, *On the Contractile Tissue of the Iris.*

According to my observation the iris is made up of tissues in this manner: on its anterior surface passes the continuation of the posterior elastic corneal layer,—the pillars of the iris, which do not terminate abruptly at the outer margin, but are gradually lost upon the anterior surface, whether this is covered by an epithelial layer, as on the back of the cornea, I am not certain. Kölliker and others say positively it is, Bowman as decidedly that it is not. In one examination of the perfectly fresh eye of the sheep I feel confident cells similar to those on the membrane of Desmours were present; in others, I have thought they were, but in very far more observations I have been altogether unable to see any. Next comes a numerous plexus of blood-vessels, radiating from the greater circular sinus, which, with frequent inosculations converge towards the pupil, at about the one-tenth or one-twelfth of an inch from which they form another vascular ring—the lesser circular sinus, which, from its knotted projections, is often very perceptible to the naked eye. From this ring other minute vessels pass to the very edge of the pupil, and, probably, in some instances, slightly beyond, for the margin is seen, when magnified, not to be perfectly round and uniformly smooth.* These vessels constitute the projecting cords referred to as being so prominent in some eyes, with them are mingled nerves and numerous delicate fibres, which, on the application of acetic acid or potass, are gelatinised, while a great number of oval and elongated nuclei are developed. Some of these fibres run concentrically, but the greater number as radii. Much of these I incline to think to be rather the coats of the blood-vessels than unstriped muscle, but undoubtedly some of these very closely resemble the fibres of the ciliary muscle, with which they must, therefore, be considered identical. Then there is another set of vessels, frequently, however, inosculating with the former, which are principally derived from the anterior ciliary arteries, and the continuation of vessels from the choroid coat and ciliary processes; these pass to the inner sinus and beyond it to the edge of the pupil. The whole is covered posteriorly with hexagonal stellate pigment and mucus which according to some, as has been mentioned, constitutes a distinct coat: while in the structure there is incorporated a good deal of pigment, which assumes the stellate form, which, however, I do not consider as consisting of true cells of this form, as has been described, but rather as resulting from the aggregation of the minute ultimate cells about the vessels and fibrillæ. Mingled with these structures is an immense number of long minute cylindrical-branched fibres, clear and glistening, with sharp-defined walls, many of them much convoluted, others lying side by side and straight (fig. 12, plate 1). They are unaffected by acetic acid, ammonia, or potassa, and are rendered very distinct by æther. They are so numerous as to form a considerable portion of the bulk of the iris. It is very difficult to pronounce upon their direction, but I believe it is from without to within; nor can I state whether they are elastic or not, but from their appearance I should regard them so; they are certainly more numerous in the outer radiating portion of the iris than in the inner concentric part, but in this they are not wanting.

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* In the Lincoln's-inn-fields Museum there are some good preparations which show well the long ciliary arteries, forming a vascular circle, from whence branches ramify over the anterior surface of the iris. In No. 1683, of the Piked Whale, they run nearly to the pupillary edge before dividing and forming a vascular ring, from whence many branches pass outwards to the outer margin, and there enter into a circular sinus. No. 1688, the eye of a porpoise, also 1689 and 1737 B, of which there is no description, where the arteries are filled with mercury, show the projecting wavy arteries with great distinctness.

The inner part of the iris, within the smaller vascular sinus, is thinner than the outer portion, and here the appearance of a concentric band of unstriped muscle is much more evident than in the outer portion. There is a distinct circular layer of fibres which surround the pupil, and in fact form it. They may be seen from either surface of the iris, but are nearer the posterior (fig. 3, plate 2). The margin is not perfectly smooth; when examined with the one eighth object-glass, projecting from it may be seen fibres, which with a little teazing out are rendered very distinct, and consist of concentric portions. These often may be seen as branched and fimbriated, exactly as represented by Mr. Lister, who, if I understand him correctly, regards them as the essential elements of undeveloped muscle, being the elongated nuclei of the cells not connected into fibrillæ,—an opinion which seems to me rather fanciful than real; as they may be seen in connexion with other portions of fibres, and appear to be only their terminal points. Amongst the other structures a large number of elongated nuclei are very evident, and sometimes cells more or less distinct are to be seen. In the calf, I have found cells of a distinct and regular form arranged in lines, very like the representation given by Carpenter and others, as the real cellular structure of muscles (fig. 4, plate 2). This part of the iris is much firmer than the outer, is not much acted upon by alkalies, and I should say without hesitation, were it not in opposition to the very decidedly expressed opinion of Mr. Bowman, the part where evidences of muscular structure in mammalia is far more distinct than in the outer. It, I think, is in this situation that in birds is principally found the striated muscle, which in them resembles that of the heart more than the large voluntary muscles. These fibres in birds are not very plentiful nor always to be easily found, unless the portion be well washed and teazed out, when with due care in the fresh eye they may be certainly enough recognised (plate 1, fig. 13).

The iris is very vascular; the arteries are derived from three sources. The long ciliary artery on each side passes, as has been mentioned, in the horizontal axis of the eye, without giving branches, as far as the ciliary muscle, in which it divides into two branches, one of which passes above, the other below, and running in the larger margin of the iris constitute, by the four uniting, the larger and outer circular sinus, from whence the branches proceed as has been described. The anterior ciliary arteries enter the ciliary muscle and iris, some join the outer sinus, others assist in forming the radiating plexus, and with it pass to the lesser sinus; while the third set of vessels are continuous loops, but not so minute, with the vessels of the ciliary processes and choroid; they are derived from the short ciliary arteries (plate 3, fig. 5, plate 4, figs. 8 and 9).

The veins run with the arteries in the iris, and terminate, some in the ciliary trunks, but most of them in the *vasa vorticosa*, and others, according to Arnold and Retzius, in the canal of Schlemm.

The nerves of the iris are very numerous; they are derived from the ciliary, and thus from the lenticular ganglion (fig. 82 and plate 3). They are flattened cords, which after entering the sclerotic coat pass in grooves between it and the choroid, to near the ciliary muscle, where each branch divides at an acute angle, and penetrating into the structure of this, divides and unites with the other branches, in such a free manner as to have given rise to the idea of this body being a ganglion. They then in numerous branches pass into the iris, where in mammalia it is very difficult to trace them, as they seem to lose their tubular character; and, although, I have sometimes thought I could follow some twigs completely to the pupillary edge, I have not been certain, and have never been able to trace them as the distinct cords described by Arnold (figs. 3 and 4, plate 3), yet no doubt can exist as to the presence of nervous matter in the pupillary edge. In birds the nerves are larger and more distinct than in mammalia, and may be distinctly seen passing from the ciliary muscle into the iris.

Though so highly organised, the iris is by no means a sensitive structure. In accidental wounds and operations, at the moment of infliction, not much pain is usually complained of, and in acute iritis the intense pain which, not unfrequently, though by no means uniformly, accompanies it appears rather referrible to other tissues than to the iris itself.

What is the rationale of the action of the iris? Probably the answer would by most be without hesitation dilatation of the pupil by the outer radiating fibres, contraction of it by the circular, both being active conditions. That the contraction of the pupil is an active condition effected by the circular muscle I think admits of no doubt, but I do not feel so sure as to the dilatation. The indistinctness of the muscular fibrillæ; the large amount of what I regard as elastic tissue in it; the great extent of dilatation, so much beyond what we know even unstriped muscular fibre is capable of, and many pathological changes, all tend to the probability of this action, being, at least in part, a physical one, due to elasticity. The iris is probably both muscular and elastic: that in the ordinary condition of the parts, when the eye is at rest and not in a full light, the two sets of elastic fibres pretty nearly balance each other, the pupil being then moderately dilated; but when the eye is in action, small or near objects regarded, or there is a bright light, that the circular muscle contracts the pupil, this being the active condition, and that on the cessation of it, dilatation ensues from the contraction of the extended elastic fibres. Thus on going from a dull room into sunshine the contraction of the pupil is active, but on passing from the sunshine into a subdued light the dilatation is passive. Under some circumstances, however, the dilatation of the pupil would appear to be active, as when the eye is adjusted to distant vision, when, *cæteris paribus*, the pupil is dilated, and certainly some other modification of the parts near the iris of an active consensual, if not volitional character, takes place.

The size of the pupil varies in a state of health, from the one-fifteenth to the one-fourth of an inch, but in disease, injury to the brain, or under the influence of different agents, it varies to a much greater extent. At the present time I have one patient under treatment whose pupil does not measure the one-thirtieth of an inch, and yet by atropine it can be dilated readily enough, but vision then becomes almost lost and contraction of the pupil is not restored for several days, and another in which a mere margin of iris can be seen, the pupil measuring very nearly if not quite half an inch; so it is well known that under the influence of opium, the pupil almost disappears, while under that of atropine or hydrocyanic acid, the iris itself almost disappears, so immensely is the pupil dilated.

Birds, it has already been mentioned, possess a voluntary power over the motions of the iris, or at least are thought to have, and that certainly striated muscle exists in its structure; but mammalia do not. Some few cases, however, are on record in which men have apparently had control over the motions of the iris. Dr. Paxton of Kilmarnock * has recently given an account of his own case, accompanied by some interesting remarks on the structure of the iris by Dr. Allen Thompson, who vouches for the facts stated. It is related that Dr. Wollaston possessed the same faculty, and if I mistake not a similar case is somewhere mentioned by Majendie. It is certain that so close a consensual action exists between the iris and the muscles of the eye-ball that no great action takes place in one without the other also undergoing a change that not impossibly attention and effort might make it in some degree volitional. Sir C. Home, on what authority I know not, declares that "many people acquire a power over the action of these muscles (the dilator and sphincter of the iris), so as to render them voluntary."* Professor Beer, of Bonn, says that by thinking of dark or light scenes he is able at will to dilate or contract the pupil through mental emotion, but not absolutely by pure volition.

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* *Glasgow Medical Journal*, January, 1857.

That the contractile power of the iris is dependent upon the fibrillæ received from the third pair through the ciliary ganglion is I think certain. Lately it has been supposed the power of dilatation is derived from branches of the spinal nerves, which, through the superior cervical ganglion of the sympathetic, pass up into the carotid plexus, and from thence by means of the fifth pair to the lenticular ganglion: a view which is supported by more than one physiologist and by different experiments, but which I think is open to objection. Experiments of such a nature are by no means to be at once taken as demonstrative; they are an important means of arriving at conclusions, but unless varied, and often repeated, and confirmed by pathological conditions, are only to be received with great caution. In this instance they are not to my mind altogether convincing. The influence of the third pair, in connexion with the optic nerve and retina, is undoubted. At this time I have a most interesting case in a gentleman who was seized upwards of a year ago with some acute affection of the brain, for which, most improperly, he was sent to an asylum, the following day the medical officer of the establishment, perceiving the existence of active disease of the brain, sent him home. He after a time sufficiently recovered to partially attend to business, and is so doing at the present time, but found his sight indistinct. This increasing, with great debility, he consulted me two months ago. The general and local symptoms all indicate organic disease near the centre of the brain; there is paralysis of all the muscles supplied by the third pair of nerves; the upper eyelids are paralysed; there is excessive divergent strabismus; and the pupil is so widely dilated that a mere strip of iris, not the one-tenth of an inch broad, can be seen. From inability to elevate the lids he cannot see, except objects close to the body below him, but when the eye-lids are lifted up, vision is almost perfect for distant objects (so much so much so that he counted the separate rows of bricks in a building some distance off), when only one eye is exposed, confused if both, from the impossibility of directing the axes of the two to a focus. Light is not painful to the retina. There is not the smallest contraction in the iris, nor do the most resolute attempts to move the eyes produce more than a very slight oscillation of the ball, except in the abductor muscle, which jerks the ball still more outwards. The effort is disagreeable: the one eye has been in this condition for several weeks, with the other he has worked until lately, but it has gradually been falling into the same condition. There is deep-seated pain in the head, want of sleep and appetite, great loss of power, more weakness of one side with pain than of the other, a little difficulty and slowness of articulation, and a protrusion of the tongue to one side.*

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* Lectures on Comparative Anatomy, vol. iii. p. 209.

In fœtal life there is no pupil, the aperture is closed by the *membrana pupillaris*, upon which vessels pass from the iris, forming a plexus not unlike in distribution those upon the posterior and anterior capsules of the lens (plates 3 and 4, fig. 9). They form an interesting object. Only the neighbouring vessels anastomose with each other, and not those from opposite sides, so that in the centre there is a spot free from vessels and towards which all the convexities of the loops present. It would appear that at this period there is no inner or pupillary vascular sinus in the iris, but that this results from the shrinking up of the vessels of the membrane. About the eighth month the membrane breaks up in the centre, the loops of vessels gradually contract, and become shorter, until, commonly at the period of birth, only a few shreds remain, floating between the two aqueous chambers; though it does happen, perhaps, more frequently than has been supposed, that at the full term of birth the membrane is more or less perfect, and does not disappear until some days after. I have more than once found it tolerably perfect in the still-born fœtus, and in animals whose eye-lids are closed at birth it is quite entire.

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* The gentleman died comatose a few days after this was written. He resided some distance from Leeds, and I did not hear of his death until some days after, or I should have requested a post-mortem examination.

The use of the membrane has not been very satisfactorily pointed out, probably it is essential to the due development of the iris in a true plane across the aqueous chambers, and serves to keep the base or foundation upon which the muscular and elastic structure are deposited of a correct form. So long as it exists entire the aqueous chamber is of course divided into two. As to the mode of its development there is some difference of opinion, some regarding it as a single membrane, derived altogether from the anterior surface of the iris; but probably the idea of Cloquet is correct, viz.: that it is double, the anterior layer being a continuation of a membrane which lines the cornea, and is reflected on the anterior surface of the iris, while a similar membrane lines the posterior chamber and covers the posterior surface of the iris, the two laminæ being at the pupil in apposition with each other. The posterior membrane is thought to be derived from the anterior capsule of the lens, and its vessels to be continuations of those of the capsule. Certainly vessels pass from the capsule to the iris, if not to the membrane. At this period there are then two closed sacs, each filled with aqueous humor, though the posterior must be exceedingly small, and the capsule of the lens nearly, if not quite, in contact with the membrane; which, as the central vessels shrink up, and the *membrana pupillaris* is absorbed, are converted into one, the two membranes are described as uniting at the edge of the pupil, and in other respects lining the anterior and posterior portions of the cavity as before. It is probably from this reasoning rather than direct demonstration in the adult eye, that so many anatomists describe the posterior surface of the iris and the anterior of the capsule of the lens to be covered by a continuous serous membrane which secretes the aqueous humor.

RETINA.

The retina is the sentient part of the eye, for which all the other textures are formed, and to which they may be said to be subservient. It is coextensive with the choroid proper; it covers the whole of the convex portion of the vitreous humor, and is covered by the choroid. It terminates in a serrated line, *ora serrata,* which is readily seen with an inch lens, just where the ciliary processes are continuous with the choroid. There is, according to some anatomists, a circular blood-vessel running near to this edge, if so, it is probably a vein, but it rather appears as a series of capillary loops of the central artery. Some of the older anatomists and opticians described the retina as being continuous over the anterior surface of the crystalline lens, an opinion which has been adopted to a great extent by Arnold, who describes and figures the retina as being continuous with the ciliary body and processes to the edge of the lens,*—*pars ciliaris retinæ* and *processus ciliaris retinæ.* This, however, is, without doubt, an error; though the retina does not terminate wholly and absolutely at the ora serrata, as is commonly described. The nervous structure here ends, but there is, continuous with the suspensory ligament of the lens, a cellular layer, as far as the edge of the lens: this is best seen after the eye has been kept for some time in spirit or Goadby's solution, by which the layer is rendered opaque and white. Its continuity with the retina may then be readily traced, and, indeed, in some eyes it looks so like a continuation of the whole retina as to render the microscope essential to prove that the nerve-structure is not so prolonged.†

The retina has, until very recently, been described as the terminal expansion of the fibres of the optic nerve into a membrane. It is, however, much more than this; it is one of the most complex, perhaps the most complex, structure to be found in the body, and instead of being thought of as simply a terminal nervous expansion, it should be regarded as in itself a nervous centre; having the fibres of the nerve expanded, it is true, in it, and by which it is connected with the brain, but possessed itself of structures and properties peculiar to it, and altogether different from those of the optic fibres, which are expanded in and make part of it. These fibres are for the purpose of conveying to the sensorium the impressions excited in the retina, but are not for receiving the impression, while the other complex structures of the retina receive and appreciate the impressions of external objects.

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* 'Icones Organ. Sen.,' tab. 3, fig. 2.

† In one instance of an alligator, I find a memorandum I made at the time of the dissection, to the effect that the retina was traceable to the edge of the lens; but as this was made before I was so well acquainted with the different structures in the retina, and the eye was not very fresh, I should not rely upon this apparent exception, but look carefully at these parts when opportunity again offers a similar creature.

The inner surface of the retina is not merely superimposed upon the vitreous body, but is organically connected with it, by a series of clear, perfectly transparent cells; while the outer surface is most intimately united with the cells forming the inner layer of the choroid. It is an extremely delicate, thin structure, thickest at its junction with the optic nerve, and gradually becomes thinner as it reaches the ora serrata, where it is not more than a quarter the thickness it possesses at the back part of the eye.*

In the living condition the retina is as nearly transparent as possible, and of a slight pink tinge, but in a very short time after death it becomes translucent, then opaque: by immersion in water it very soon becomes so; and by spirit, heat, and all chemicals which coagulate albumen, it is immediately rendered quite opaque and white. In the fresh eye it is perfectly smooth, but, in consequence of evaporation from the eye, it is at the period when human eyes are commonly dissected found in irregular folds. The pink tinge of the fresh retina is due to the blood which it contains. It is a very vascular structure, deriving its supply of blood from the central artery of the retina, and, not improbably, some of its nutriment, though no vessels, from the choroid coat.

So numerous and complex, so minute and fragile, so transparent and changeable, so intimately connected and mingled together, so quickly altering after death, and yet, at least in man, so difficult to obtain immediately after death, so instantly and most importantly altering on the addition of almost every agent that may be employed in assisting in the examination of other tissues, that it is no wonder almost every description of these structures is different from others; and that one microscopist should find appearances which others have not. Hence, notwithstanding the careful labours of many of the most eminent anatomists and observers, it is very doubtful if we are yet in possession of the real living structure of all the parts in this wonderful tissue. Certain I am that many statements are incorrect, that *post-mortem* changes have been confounded with normal living forms, and alterations effected by reagents have been described as natural conditions. Thus, while it is easy to say that some of the descriptions are certainly not correct, it is by no means so easy to feel certain that one's own observations, however carefully and repeatedly made, are not also open to error. While, therefore, I have taken all the care I can, and spent much time upon the investigation, I would wish to be understood where differing from other anatomists in the description of these parts, as doing so with the greatest deference, and with the full recognition of the weight attached to their skill and experience in the use of the microscope, and as only stating that which I believe to be the forms during life of these minute structures, and not as asserting dogmatically what is incapable of dispute.*

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* Kölliker says, "Its thickness is at first 0·1 of a line, but as it extends anteriorly it soon diminishes to 0·06 of a line, until ultimately close to the anterior border of the retina it is not more than 0·04 of a line in thickness." ('Kölliker's Human Histology,' by Busk and Huxley, vol. ii. p. 369.)

The retina consists of several layers superimposed upon each other; commencing externally, these are—

1. The columnar or bacillar layer, rods, Jacob's membrane.

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* I believe the only way to examine the retina unchanged is to do so *immediately* after death, and without the addition of *any substance whatever*. So rapidly do the rods undergo change, that in a few hours they are completely altered; and not unfrequently even when taken from the living eye, they are seen to alter while under examination. I know of no fluid which does not more or less change them. Even chromic acid, which Kölliker so extols, is not without greatly modifying influence upon the true retinal elements; and water *immediately* materially alters, and soon quite destroys the rods, and alters the granules and bulbs. It is extremely difficult purposely to make a section sufficiently thin in the fresh retina to examine it in profile; and, if expanded and dried, it requires maceration to render it fit for examination, by which the structures swell and alter irregularly, whatever fluid be used, so that the natural forms are not obtained; but these examinations are important as helping the inquiry, and by employing different fluids the one error may to some extent correct the other. The fluid which I have found to preserve the retina in the most natural condition for the longest time, is Goadby's solution, No. 1, diluted by one half. My experience of chromic acid is much less favourable than I had been led to expect by the statement of Kölliker and others. It is true it renders the cerebral elements of the retina, the nerve-fibres, the nucleated cells, and the granules or granular cells, more distinct; but its action upon the rods and conoidal bodies is very considerable—if strong, there is one confused fibrous mass, coloured yellow by the acid; if much diluted, the rods break up into discs and granules, and the cones soon swell and disintegrate as with water. I doubt if its action be greatly superior to that of diluted acetic acid, which has the advantage of being colourless.

2. Bulbous or conoidal bodies.
3. Granular layers.
4. Nucleated vesicular layer.
5. Vascular layer.
6. Fibrous layer.
7. Hyaloidal cellular layer.

1. The outermost layer of the retina is really a wondrous structure. It is quite peculiar to the retina, but is found in all animals where there is a retina, even in the eye-dot of the "blind mole." It consists of minute cylindrical bodies as innumerable as the sand upon the sea-shore. They are RODS or COLUMNS, arranged side by side, and stand perpendicularly to the centre of the eye; the outer ends are in close connexion with the choroid coat, the inner ends rest among the granules which form the third layer; they consequently stand at right angles to the fibrous expansion of the optic nerve. They may be traced uninterruptedly from the expansion of the optic nerve to the ora serrata; they are considerably the longest at the former situation, and appear gradually to decrease in length towards the fore part of the retina. They are so closely arranged as to constitute a complete coat. In man, mammalia generally, reptiles (except the chelonian), and fish, they appear to be perfect cylinders, with clear, distinct, straight, transverse ends. In chelonians and birds, there are a few cylindrical, but they are for the most part bulbous or conoidal; the larger end being outmost. They have been sometimes described as six-sided prisms; undoubtedly not unfrequently they appear hexagonal—this, however, merely arises from their being compressed against each other, where not so they are perfectly round. In the frog and the toad by far the greater number are perfect cylinders, but I have seen some few amongst the mass with one end broader than the other. They are solid, perfectly transparent, highly refractive rods, quite straight in the living eye, but they very soon become variably distorted, as bent at right angles, particularly towards one extremity, the outer, or curled up at one end, like the hook of a walking-stick, as represented as the normal condition by Hassall; but of which not a trace is to be found in the eye of an animal just killed. They then curl up into oval or circular rings, so as to look very much like cells, and may easily be mistaken for blood-cells; occasionally they split longi-

tudinally, but far more commonly they become marked by transverse striæ and look like connected discs, then granular, and ultimately break up into transparent granules, and altogether disappear, so that in six, twelve, or twenty-four hours after death, hardly a straight, clear cylindrical rod is to be seen, and frequently in forty-eight hours or less not a trace of them is left.

They are very flexible, and may be seen to bend on encountering any obstacle—as when detached from each other they float about—and immediately this is passed, to again become straight; but I do not think they are elastic, that is, compressible. They are, at the same time, very brittle, and most easily break. They appear neither to attract nor repel each other, but when brought into contact they often adhere by the parts which actually touch, so that if they happen to come end to end, two may easily be mistaken for a single long rod. They are largest in reptiles generally, and of these in the frog; next in fish, and smallest in man and mammalia. Though their size varies in different creatures, it bears very little proportion to the size of the animal or of the eye-ball. Thus the rods of the frog, toad, and water-newt are as large or larger than those of the alligator; of the sparrow and canary bird as those of the fowl or turkey; of the duck as those of the swan; of the carp, trout, eel, and herring as those of the halibut, salmon, haddock, and cod. Those of the rat, mouse, and mole are nearly as large as those of the sheep, ox, and horse; of the monkey as those of man; indeed those of man, if anything, are smaller, and, I think, more numerous than in almost any other creature.

I have stated that I believe these in the living eye to be straight cylinders, but this is not the usual description. Hassall has described and figured them as curled into a knob at the outer extremity. This is a very common appearance when the eye has not been examined until the animal has been dead a short time, but certainly does not exist in the living eye; and may often enough be seen to form while the examination is going on; especially on the addition of dilute spirit, or after the unopened eye has been immersed in it for a short time. On the other hand, Hannover, in his beautiful plates ('Recherches microscopiques sur le Système nerveux'), has described and figured all the rods as terminating outwardly in a conical extremity; this being in some animals prolonged into a long delicate filament, which is, he says, received into a minute sheath formed in the choroid coat, whereby the two tissues are organically connected together. In this he is followed to some extent by Mr. Bowman.

For this cone at the outer extremity of the rods and its surmounting filament, I have searched most diligently, indeed I may almost say wishfully, as desiring to see what two such authorities have described as the true form, but I must confess to have failed. True, a short conical appearance is often to be seen at one or other extremity of the rod, but I have never been able to satisfy myself that it is not an optical effect, from the end not being in focus, for almost invariably I have found that by focusing the conical appearance disappears, when the rods are single, and while they are *in situ;* supposing them to be conical, and the cone enclosed in a sheath of the choroid, I do not see how it is to be observed, at least I have failed in the fresh eye, and so distorted do these small bodies become by drying the retina, and subsequently moistening it, or by the addition of any reagents, that I place very little reliance upon appearance then presented; nor do I think the statement of these observers, that the great disposition there is for the rod to break at the precise point where it becomes conical, is sufficient to account for the difficulty of finding the cone; for in this case the cones ought to be found separate in some abundance, considering the enormous multitude of rods; which they are not. Besides which, while they state that the *inner* end of the rod is perfectly straight, and the *outer* is conical and pointed, imbedded in the choroid, Hassall describes the outer ends of the rods as of a globular or oval shape, and Kölliker declares the opinion of the conical form of the *outer* end to be a mistake—that, in reality, it is perfectly flat and straight, while the *inner* end is not only conical, but sends a filament so prolonged as to pass entirely through the outer layers of the retina to the inner surface, where it terminates in radiating fibres as first described by H. Müller. Kölliker would appear to regard the rods as cells filled with fluid, for he says, that on breaking up, "they allow clear drops to exude, which are often met with on the external surface of the retina in vast quantity." This is contrary to the observations of most others, and does not correspond with what the rods appear to my eye, as above stated. By some the rods are described as cylinders, terminating in an expanded head like a nail; very often rods may be seen of this shape. I have seen this particularly in the rat; but it simply arises from the granule to which the inner end of the rod is attached still adhering to it; by watching for a while, it will be seen to become detached; often too they appear conical or swelled out, from a granule adhering to some other part of them.

In all birds, and in the turtle, the straight cylindrical rods are comparatively few in number, the greater part of them are conoidal or fusiform in shape, the base being without, and they are surmounted by a highly transparent coloured globule, which is closely attached to and partly imbedded in the end of the rod. The number of the true cylindrical rods in aquatic birds, as the duck, goose, or swan, appears to be very much less than in land-birds; indeed, in some it is questionable if all the rods are not more or less conoidal in shape, but they are so to a less extent than are those of land-birds. The globules are evidently cells filled with a coloured fluid, which reflects light almost like oil, but is not oil; for the cells are not soluble in either spirit of wine, or dilute potash, ammonia, acetic or chromic acids; and when the globules are crushed, and the coloured fluid has run together and dried, it is soluble in water, while the dried globule, by immersion in water, swells out to even a greater than its normal size. They are unaffected by immersion in boiling water; they are well seen by the addition of chromic acid; and then, if liq. potassæ be added, the colour is destroyed, but their shape and size are well shown; the rods are dissolved, and thus they are left free. Many of the globules are of a beautiful ruby red; others, and the greater number, three or four to one, of a canary yellow, some approaching to a green tinge; some few I have seen of a decided green colour, and in some the colour is so pale, as to be hardly perceptible. Though the yellow are the most numerous, the ruby are for the most part the largest. There is no fixed relation either in number or size, nor are those of the same colour always of the same size, varying in the bird from $\frac{1}{6000}$ to $\frac{1}{12000}$ of an inch; and I think the size, number, and relative proportion of the two colours differ in different parts of the same retina. In a guinea fowl, I found the globules very nearly uniform in size, about the $\frac{1}{5500}$ of an inch, and the globules of pretty nearly the same tints of ruby and canary colours. I have found there is more variation in size and colour of the globules in young fowls than in old. Though closely imbedded in the rods, they easily become detached and float about; they are also attached to the choroid coat, but not so intimately as to the retina, for in separating it from the retina they always adhere to the latter. They are much more persistent than most of the other elements of the retina, and may be preserved, when dry, for some time. Hannover, who was the first to describe these bodies, has figured the ruby as attached to what he calls *cones jumeaux*, and each of these as surrounded by six rods, surmounted each by a yellow globule, forming a setting for the ruby. I do not think any such precise relation in number or position exists.

I know of no more beautiful object under the microscope than the outer surface of the retina of a Cochin cock, guinea fowl, or turkey, and particularly of a turtle. Could a lady deck herself in jewels so brilliant and beautiful, she would esteem herself the gayest in a ball-room. I know of nothing except the corneal facets of a coleoptera to compare with it. In some birds the colours are much more intense than in others. I thought it possible the colour of the feathers might have some connexion with this, but it does not appear to have; for instance, the yellow globules of the canary bird are not more numerous or intense than those in the sparrow; the ruby in the brilliant game cock than in the grey guinea fowl: nor does there appear to be any difference in two similar birds of different plumages, as in a white and a variegated fowl. However, I do not think, in aquatic birds, they are so brilliant in tint as in land-birds, nor is there altogether so much difference in the size of the two-coloured globules. But, of all creatures which I have examined, the coloured globules are the largest and most distinct in the green turtle. The ruby are, as in birds as a whole, larger than the yellow, and are more uniform in colour; whereas the tint of the yellow, like their size, varies very much, from a full canary, to nearly or completely colourless white.

Similar, but not nearly so perfect globules, are found in some other reptiles. I have seen them in the toad and the frog; in the latter of which they are most distinct; and in some fish, the eel for instance, globules of the same general size and appearance, but of a brown colour, more like those of the choroid, but larger, are to be found. So in some mammalia brown globules of the same size and general characters are to be sometimes sparingly met with. In viewing these coloured cells they often appear as containing a circular nucleus, which is, however, only an optical effect, for by adjusting the focus it always disappears. Hannover describes this appearance as resulting from the cells being conoidal, and both ends being seen at the same time. In some few cases I have thought the detached cells conoidal, but this is so very rare compared with the frequency in which no doubt can exist of the generally perfectly globular character of both ruby and yellow cells, that I rather incline to attribute it to the end of the rod in which the cell is partially imbedded being seen, than to the cause mentioned by Hannover. In one bird, the common fowl I believe, the globules had a short projecting spur, which was received into the end of the rod, and which might give rise to the appearance; and in the turtle I have seen a few of the globules with a similar minute projection on one side, as though it had been imbedded in the conical rod; in the swan, where the globules are not particularly well developed, I have found some few fusiform in shape.

The use of these globules I can offer no conjecture upon.

Internally the rods pass in amongst the granules, and the end of each rod appears to rest upon and be connected with one or more granules. Externally the end of the rod is, I think, implanted upon the cellular or epithelial, as it has properly been called, layer of the choroid; the clear portion, which has been regarded as the choroidal cell, being that where the rods have adhered; for there can, I think, be no doubt that the retina and choroid are organically connected together, the rods probably deriving their nutriment from the choroidal vessels; no blood-vessels are to be found in the columnar layer itself.

The rods are evidently a nervous structure, *sui generis*, their whole appearance indicates this, and probably they are intimately connected with the sense of vision; but in what way they act, whether as independently perceiving the image, which the nervous fibres only place in relation with the sensorium, which then intelligibly appreciates the information, or only as affording a suitable surface for the imprinting the image upon, which the nerve-fibres then convey to the sensorium to be there perceived, it is premature to discuss; but their complex character would rather point to their possessing some independent function, than to their being the mere recipient surface for an image, to be thence conveyed to the brain as the sole sentient part. Whether they are the real terminal expanse of the optic fibres, as Kölliker seems to suppose that Müller's and his own observations indicate, is, to say the least, unproved; nor does it appear to be necessary for our estimate of the importance of their functions. That they are in connexion direct or indirect is more than probable, but that they are to be regarded as the expanded nerve-ends does not seem so probable as their being peculiar nervous structures, having separate and individual power. Where there is the greatest amount of intelligence they appear to be the smallest and most numerous.

This is the structure which was first pointed out as a distinct layer of the retina by Dr. Jacob, and has since been known as the membrane of Jacob; though its nature was not, indeed could not have been, known by him. He regarded it as a protecting membrane, interposed between the nervous retina and the choroid. This notion became commonly adopted, and was much extended by other anatomists, some of whom, particularly the late Mr. Dalrymple, argued very strenuously for its being a true serous membrane, constituting a shut sac like the pleura or arachnoid, a view he supported by arguments, drawn from analogy and pathological conditions, which he thought satisfactory. Of course, now that its structure is so far known, this idea must be altogether dismissed. It is most easily detached in translucent shreds from the other elements of the retina as soon as decomposition begins, or on immersion in water. When this occurs it is evident that the structure has undergone a change; the rods are then altered. (Plate VII., fig. 3.)

2. The *cones* or *bulbs* constitute the second layer of the retina; however, as these bodies when found are always placed amongst the rods towards their inner end, they are hardly to be considered as forming a distinct layer, though for convenience of description it is necessary to speak of them separately. Regarding them there is even more difficulty and uncertainty than with

the rods. As to the latter no one can doubt their existence in the whole of the vertebrate division, whatever differences of opinion may be entertained as to their form and connexion, but the very existence of the bulbs, in by far the greater number of animals, is open to considerable doubt; and of their form, number, and connexion, to much more. Hannover, who has given the most elaborate description and figures of them, from their form, denominates them *cones jumeaux*, *coni gemini*—twin cones, and says they consist in the fish, where they are most developed, of double cylindrical bodies, two or three times as large as the rods, placed side by side: that each of these cylinders is divided into two equal parts; an internal one, smooth and round, as though enclosed in a delicate capsule, separated from the external half by two transverse lines; and an external moiety, composed of a mass of minute granules, and terminating outwardly in two conical points. That after a time, or on the addition of a liquid, the inner cylindrical portion becomes larger and fusiform, bilobate like a coffee-berry and granular, while the conical points fall off, curve themselves into hooks, and often altogether disappear. That the *cones jumeaux*, like the rods, are planted perpendicularly to the other elements of the retina and choroid, that each *cone jumeau* is completely surrounded by a regular number of the rods, and that each of the two conical points is, like the filaments of the rods, received into a membranous sheath of the choroid, as the corolla of a tubular-shaped flower is surrounded by its calyx, but that the sheath without colour in reality encloses the entire cone. That the cones are wanting in all reptiles except the chelonian.

In birds Hannover considers bodies very different in form as the *cones jumeaux* (those which I have called conoidal or fusiform rods); because they are sometimes surmounted by two coloured globules and are surrounded by the rods. He states, as already mentioned, that the citrine-coloured globules are situated at the outer end of these cones.* In mammalia he describes the *cones jumeaux* as being shorter than the rods, with their external ends terminating in two short and abrupt points.

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* In the text Hannover states that the *cones jumeaux* are surmounted by the citrine-coloured globules, while in his figures of these parts, and in the description of them, he represents the cones as surmounted by the ruby-coloured globules. ('Recherches microscopiques sur le Système nerveux.')

Mr. Bowman was the first to describe the bulbs in the human retina. He says they are solitary, globular, or egg-shaped, transparent bodies, sometimes having a small blunt spur upon them, turned towards the choroid, placed at regular intervals amongst the rods, much less numerous than the rods, of larger size, but not so long, and sessile upon the granules. Unlike Hannover, who believes these bodies not to exist in reptiles except the chelonian, Mr. Bowman thinks they not only do exist, but that in the frog they are nearly as numerous as the rods.

Hassall, in his description of the microscopic anatomy of the eye, makes no allusion to the existence of such bodies as cones or bulbs, which evidently he had not detected.

Kölliker's figures and descriptions of the cones are altogether at variance with those of both Hannover and Bowman. He states that the cones are rods, which, instead of a filament at their inner extremity, are furnished with a conical or pyriform body. That each cone consists of an *external*, thicker and longer finely granular extremity, more or less ventricose, and which passes into a common rod; and an *inner*, shorter portion, in which an elongated or pyriform, more opaque and brilliant body is enclosed; the cones being, like the rods, continued by fine filaments into the deeper layers of the retina.

I have searched most carefully for these bodies in the eyes of many animals, but I cannot say that I have satisfied myself of the existence of any bodies such as have been described in the perfectly fresh eyes of any creature, except fish, and even here, they do not, so far as I can ascertain, exactly correspond with the description given by Hannover; and in the turtle, where the bulb is distinct. In sections of retina from the higher animals, which have been dried and moistened by various reagents, or even fresh retina treated with dilute chromic or acetic acids, it is not difficult to find various-shaped particles, which may be supposed to be these bodies, but inasmuch as they are not to be detected, so far as I can ascertain, in the perfectly fresh eye where its retina alone is examined, I am doubtful of their actual existence as distinct bodies. There is no difficulty whatever, when regarding the undisturbed external surface of the retina of either reptiles or mammalia, of recognising the forms figured by Hannover and Bowman, which they consider the cones or bulbs not in focus, but I have always failed in detecting the appearances represented by them in profile, and I am more inclined to think the bodies seen at a deeper level, and out of focus, when the outer ends of the rods are in focus, not as cones or bulbs, but as the outer portions of the granular layer to be presently described, and upon which the ends of the rods rest, indeed are closely attached to ; or as the inner ends of the rods themselves, not in focus.

That coffee-shaped granular bodies, often more or less bilobated, are to be seen in the retina of many animals is certain, but I have so commonly seen rods to assume this form while under the microscope, that I strongly suspect many of the forms which have been described as cones are really only modified rods. That bodies at all resembling the *cones jumeaux* of fish, which may be regarded as the type of these cones, exist in mammalia or most reptiles, I am persuaded is incorrect. I have examined the eyes of the alligator, the chameleon, the newt, the frog, and toad, the last three over and over again, both young and old, fresh and dried eyes, without being able to detect any. Moreover, Hannover's own account of what he calls these bodies in birds shows them to be altogether different structures from what he describes under the same name in fish. In birds there are, as has already been stated, numerous conoidal bodies surmounted by a brilliant coloured globule, but they appear to differ very little from rods, and their broader end is external, while they are in no respect double, nor have they any sharp conical points, either single or double.*

In fish there certainly exist imbedded between the deeper ends of the rods, and like them, resting upon the granular layer, a number of conoidal bodies of larger diameter than the rods ;

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* To describe bodies which differ so essentially as the *cones jumeaux* of fish, and the elongated bodies which are surmounted by a coloured globule in birds, as the same structures, appears rather as a predetermination to find an uniformity of structures, than a simple representation of what really is seen—an attempt to generalise, than a record of what actually exists—the small ovoid bodies more resemble the *cones jumeaux* of fish than do the conoidal rods.

each consists of two portions; an oval bulbous part when two are pressed together, globular when they are single; and a conical one of about equal length. The point of junction is marked by a very fine transverse line, and where, commonly, but not invariably, a separation takes place. They reflect the light strongly, and are at first perfectly transparent, solid, and homogeneous. The conical end breaks up into discs, and then granules, exactly like the rods, while the bulb swells and becomes less transparent, then granular, often irregular in shape, not unfrequently it splits more or less completely into two portions, and then disappears in granules. When the conical leg has become detached and the bulb somewhat split, it resembles much a coffee-berry. These changes occur within a very short time after death. I have seen them take place while the part was under examination, within fifteen minutes after the fish had been swimming in the water. They occur immediately on the addition of water, and many other reagents. These cones lie with the bulbous end resting upon, and connected with, one or more granules, the narrow end always being outwards. They are closely connected with the rods. There does not appear to me to be any such regular relation in number and arrangement between them and the rods as is described by Hannover; they often are solitary, but very commonly two are side by side, when they may closely adhere by their sides, which are flattened as by pressure, and which has probably given rise to the idea of their being double, but they may be separated without any division of structure in the greater number of fish, though perhaps not in all. The cones are, I believe, commonly single, and I do not think they are enclosed by any sheath from the choroid; indeed, in some fish they do not appear to reach the outer surface of the retina, being shorter than the rods, as in the golden carp; while in others they are quite as long or even longer, as in the cod and whiting. The relative proportion of them and the rods appears to differ in different fish. In the sand-dab, *Platessa limanda,* and the Ballenwrasse, *Labius maculatus,* the cones are comparatively few; while in the whiting, *Merlangus vulgaris,* and the little weaver, or venom fish, *Trachinus vipera,* they are much more numerous; in the mackerel, *Scomber scomber,* they are very large. In some portions of the same retina they also appear more plentiful than in others, and in some fish, as the golden carp, *Cyprinus auratus*, the venom fish, and the cod, they appear more distinctly as single bulbous bodies, often two lying close together, having each a single conical projecting part; while in others, as the whiting, the bulb more commonly appears as single at first, with two conical projecting parts, and subsequently to split into two portions. The conical portion very closely resembles in character the rods, while the bulbous part more nearly approaches the granules. Can they be regarded as rods in the process of development? By water they are immediately broken up; by ether much distorted, and then destroyed; by ammonia they are instantly (as are the rods) dissolved; by acetic acid they are also destroyed, and only a clear globule left. Chromic acid also acts upon them, if strong it distorts them much, if dilute it acts as water; acetic acid has a similar action.

The retina of the turtle, if examined instantly the animal is killed (for like all others it changes in a few hours), is a very interesting sight. The outer surface is composed of conoidal rods, in shape very like those of a bird, and like them surmounted by brilliantly coloured globules, partially imbedded in the rods. These rods are of large size with the narrow portion inwards, and between them lie a number of oval bodies, which are clearly the bulbs of Bowman. They do not reach the outer surface of the retina; they are clear, transparent bodies, exactly in texture like the conoidal rods, and like them, after the lapse of a short time, or immediately on the addition of almost any substance, becoming granular. There are also to be seen a great number of ovoid bodies of nearly the same size as the bulbs, surmounted by coloured globules like the conical rods; whether these are bulbs with coloured globules attached, or whether they are altered rods, with the inner narrow part detached, I am not able to satisfy myself, but I incline to the latter opinion, for they cannot be seen *in situ*; and certainly in many instances, the conoidal rod appears with the outer part swelled out into a granular bulb, while the inner part is detached and breaks up into small discs and granules before disappearing, but, on the other hand, the end of many of the bulbs as they float about appears perfect. They carry ruby and canary coloured globules of various sizes indifferently. I have never seen two globules attached to either one rod or one bulb (as Hannover says occurs), but I have often seen a loose coloured globule accidently become attached, or the globules of two neighbouring bodies so lying as to require great care to distinguish as belonging to two different bodies. There are a few cylindrical rods, some of these are long and narrow, and appear to lie intermingled with the conoidal rods, while there are more which are shorter and thicker, and appear to be the inner ends of the altered conoidal rods broken off, and would thus resemble the conical portion of the *cones jumeaux* of fish—except that in fish the ends certainly are external, while in the turtle these portions as certainly lie internally; and in fish the bulb breaks longitudinally into a coffee-berry shape, in the turtle it does not. There are few of the larger granular cells in the turtle as in fish; but the inner finely granular layer of cells is seen, as are the nerve fibres. (See Pl. VII. where these bodies in the natural and altered condition are shown.)

3. The *granular*, as it is called, forms the third layer of the retina. The name is not a very correct one, for these bodies are certainly not granules, as they have been described, but are cells filled with highly refractive, solid, granular nuclei. The walls are so thin and easily ruptured, that, after a time, or when reagents are applied, or insufficient power is employed, only granular matter is to be found; but when a perfectly fresh eye is examined with an eighth glass, or still better a twelfth and an achromatic condenser (see Pl. X.), not the least doubt can be felt as to their being cells filled with granules. They are usually irregular in outline, probably from compression against each other. They are found in all animals who possess a retina, but very far less in number in fish and reptiles than in man and mammalia, where they exist in enormous multitudes. They appear of pretty much the same size and character in most animals as seen on the slide by transmitted light. They are of a pale yellow colour, and refract the light strongly like oil, their size varies considerably, some measuring $\frac{1}{5500}$, while many are not nearly half this size, some not more than $\frac{1}{20000}$ of an inch. They bear a strong resemblance to, and are probably identical with, the cells found in the cineritious matter of the cerebral convolutions. They lie between the rods, which rest upon their

outer surface, and the fibres of the optic nerve, and constitute in mammalia a considerable portion of the thickness of the retina, though not so much as the rods do.

Bowman and Kölliker both describe the granules as consisting of two layers, separated from each other by an indistinct fibrous layer, the outer of the layers being the thickest; but they are opposed to each other as to the size and shape of the globules forming them. Thus Bowman describes the granules forming the inner layer as smaller than the outer, of a flattened form, like pieces of money (hence named by him nummular layer), with the flat surfaces corresponding with the thickness of the retina; while Kölliker says the inner are larger than the granules of the outer layer, and arranged with their long axes in the direction of the thickness of the retina. If a section of the dried retina of man, the sheep, or the ox, be examined with water or dilute spirit, there is no difficulty in perceiving this irregular line of very minute granular matter and indistinct fibres with flattened globules arranged horizontally in the length of the retina, as described by Bowman, and not vertically in the direction of the thickness, as figured by Kölliker; but it is by no means so easy to detect this separation into two layers in the perfectly fresh retina. I have sometimes fancied it was to be seen in the bullock and sheep, but I have so often not been able to find it, that, knowing how greatly every portion of the retina is changed by all fluids, and how little dependence is to be placed in appearances there found, I feel doubtful if there really be two layers. The globules placed most internally are smaller than the external. It is, I think, in the innermost part of this and the next layer that the capillaries of the blood-vessels are principally situated, though Bowman says, they have no blood-vessels, and certainly none appear to be distributed in the mass or thickness of the layer. On the addition of water and many other fluids, the globules separate from each other, float about, dilate, rupture, and disappear, leaving only fine granules, which also dissolve. They are rendered more distinct and refractive by dilute acetic and chromic acids, in which they are well seen.

The rods rest upon and are imbedded amongst them, each rod being intimately connected with one globule, which often remains attached to the end of the rod when the rods are detached from each other. This has given rise to the impression of the rod having a head like a nail, but in a few minutes it usually becomes detached, and is then seen to resemble the other globules. It may be doubted how far the connexion is organic or not, as the same globule may be seen, if it happen to come in contact with another rod, to adhere to any part of its surface.

4. On the inner surface of the granular or nuclear layer is the *vesicular layer*—"grey vesicular matter of retina"—"cineritious cerebral substance," which is a very thin layer, composed of finely granular or cellular matter, of apparently the same nature as the last, and probably more correctly to be regarded as its commencing portion than as a distinct structure, in which also are numerous larger and clear transparent cells with large eccentric nuclei and nucleoli, identical with those found in the cerebral convolutions. It is very difficult to see these brain-cells *in situ* in the fresh eye, but floating about they are readily seen; and in a successful examination they may be seen forming a layer in which the fibres of the optic nerve are imbedded and expanded. Plate VII.

In this layer, Bowman, Kölliker, and Hassall all describe, as being found, besides the circular brain-cells, caudate ganglionic cells. Hassall says only to be found in man; Bowman in man and the horse, amongst mammalia, but particularly well developed in the turtle; while Kölliker figures those from the ox with very long processes, and his description would inferentially lead to the supposition of their being generally distributed. Bowman says they do not contain any pigment, while Hassall represents them as altogether dark, and Kölliker as containing pigment in the body of the cells, with the large central nucleus transparent. Hannover, in his elaborate account of the retina, makes no allusion to any such cells, yet he was perfectly familiar with the character of caudate nerve-cells, for he has figured them as seen in different parts of the brain and spinal marrow, and therefore we may conclude he either had not found them or does not believe in their existence.

I have searched most carefully, over and over again, for these long caudate cells in the eyes of man, many mammalia, various birds, reptiles, and fish, and particularly in the almost living eye of the turtle, and must confess, like Hannover, have failed to find them in the perfectly recent eyes. When reagents are employed, when the retina has been dried and moistened with water, or the retina examined is not from an animal just dead, not the same difficulty exists; large, irregular, more or less caudiform cells are then abundant enough. I am therefore, unwilling as I am not to see what such competent observers speak unhesitatingly of, constrained to doubt if cells such as figured and described, with many long caudate processes, continuous with the nerve-fibres, do really exist in the living eye.

There are, however, constantly found, particularly in the eyes of mammalia, cells of various sizes; some large, very much resembling in form, only perfectly transparent, epithelial cells. They are flat, irregular, contain nuclei and fine granules, lie singly or in groups overlapping each other, and are in connexion with, if not imbedded in, as I believe, the granular layer, which they so much resemble, that unless caught detached from it, at first, until the eye is familiar with their indistinct outline, they are very difficult to recognise. I give figures of these cells from the retina of the human fœtus, the pig, the ox, and the sheep, all just dead. (Pl. VII., fig. 7.) They are, probably, in composition, similar to the granular cells, and like them break up and disappear. There is, certainly, no pigment matter in them; and whether they are the cells described by Bowman, Kölliker, and Hassall as the caudate ganglionic, I am uncertain, but believe them to be. In which case, either I am wrong, in being unable to see the prolongations, or the cells described by them are modifications produced by the reagent employed, which I am inclined to suspect to be the case, seeing that I have often found the angles much prolonged when reagents, particularly chromic acid, have been employed.

5. *The fibrous layer* is composed of the filaments of the optic nerve. This nerve, which consists of nerve-tubes and cerebral cells, enters the ball of the eye through the cribriform plate of the sclerotic coat, with which the fibrous sheath of the nerve-fibres becomes confounded, and then through a narrow single aperture in the choroid coat, which is closely, but not organically, connected to the nerve. This entrance varies in its relative situation in different animals; in man, being to the inner

side, and below the axis of the ball. The nerve here forms a slight mammillary projection, in the middle of which the central artery of the retina is seen. From this spot the nerve-fibres expand in every direction, forming a complete layer upon the outer surface of the hyaloid membrane.

The fibres pass as far forwards as the ora serrata, but as yet the exact mode in which they terminate is unknown; some observers have asserted that they form loops and return upon themselves, others that they are lost in the other elements; but I believe no one has demonstrated their termination. My own impression is, that these fibres are of different lengths, and successively terminate as they pass forwards, by being lost or continuated into the true retinal elements, the granules being the connecting medium between the nerve-fibres and the rods: and that the number of the fibres at the anterior part of the retina is much less than at the posterior, not merely because in forming a continuous expansion over a larger area necessarily there must be fewer fibres in any given space than there is in the smaller, but because the fibres are continually terminating, so that they are really fewer in number in the anterior than in the posterior part of the retina.*

The fibres lie to the inner side of the granular layer, which separates them from the rods, and they are, as it were, imbedded in the vesicular layer, which, without care, always renders the fibres indistinct. These may be seen in man, animals, birds, reptiles, and fish, on both sides of the fibres. (See Pls. VII. and VIII.)

Much discrepancy of opinion prevails as to the exact nature of these fibres. Hassall and Bowman assert that they are flattened solid fibres of grey matter, not tubular, the white nerve-matter ceasing as the nerve passes through the sclerotic coat, or almost immediately after it has entered the eye, and that in passing forwards they anastomose, so as to form elongated meshes, in which nucleated vesicles appear. Hannover states that the fibres in the retina appear to possess greater consistency than they do in the trunk of the nerve itself, but otherwise have the

* Instead of speaking of the fibres as terminating in any of the retinal elements, it would doubtless be more correct to speak of them as arising from or being continuous with them, the optic being an afferent nerve.

same character. That they proceed forwards in straight lines without subdividing or anastomosing, and never become varicose. (The latter statement he modifies in a note, and allows that they do, when not in a natural state, become varicose.) Kölliker says, each fibre enters the eye without its sheath of connective tissue, independent of the others; that, radiating in all directions, they constitute a continuous membrane as far forwards as the ora serrata, running parallel to each other, or inosculating at very acute angles, are without nuclei, and form frequent varicosities. He styles them the horizontal fibre system, in contradistinction to the rods and cones, which he calls the radiating fibre system. My own observations agree more nearly with those of Hannover and Kölliker, than with Hassall and Bowman, though not exactly with either. If the formation of varicosities is to be regarded as showing the tubular character of nerve fibres, I can entertain no doubt that those of the retina are as much tubes as those in the optic nerve, with which I believe they are directly continuous, and also possess the same characters. I have seen the fibres in the retina in man, sheep, oxen, birds, reptiles, and fish become varicose while under examination; the addition of a little water, dilute acetic acid, or mere variation in the pressure, will make them so at once, and often after being in weak spirit for a short time they are found so, particularly when the cerebral cells are gently removed before examination. When a particle of the optic nerve, and another of the retina, of perfectly fresh eyes of almost any mammal or fish, are examined with the assistance of either very dilute ammonia or chromic acid, it would be very difficult to point out the difference in the fibres of the two; their size is the same; and with those from the retina, perfectly clear cells with double walls, different from the nucleated cerebral cells forming the fourth layer of the retina, but perfectly like those in the optic nerve, may be found. In the retina the fibres are somewhat wavy as they pass forwards, they reflect the light strongly, and at times, though I think, not very frequently, they form anastomoses with each other; or at any rate appear to do so, at long intervals, and at acute angles; and my impression is, they terminate in the granular layer, though this is by no means demonstrated.

In the fish these fibres are larger than in mammalia, not so distinctly tubular, run straighter, are not seen to inosculate, and do not, so far as I have observed, so readily become varicose, though they sometimes do, as in the cod (Pl. VIII. fig. 10), altogether presenting more the character of grey fibres, without the white tissue, than in higher animals. The optic nerve projects further into the eye of fish than it does in them. As the retinal fibres appear to me to be identical in structure with the nerve-fibres, so I believe them to be in function, and to merely convey the impressions to the sensorium which the true retinal elements perceive. This would satisfactorily explain why the part of the eye-ball where the nerve enters it, and where only nerve-fibres exist, must necessarily be insensible to visual impressions.

6. *Hyaloidal cells.*—On the inner surface of the fibrous layer, interposed between it and the vitreous humor, is a layer of perfectly clear, transparent cells, having very thin walls, free from nuclei, but which after a time become very delicately granular. Hassall describes them as situated on the outer surface of the fibrous layer, and thus in the texture of the retina, which is certainly wrong, while Bowman considers them as part of the hyaloid membrane. Whether they should be regarded as part of this or of the retina is doubtful, though, as they seem to be more intimately connected with it than with the hyaloid membrane, I incline to think them a part of it. They appear to be the medium of connexion between the two, and serve to organically unite them. When detached they are perfectly globular, but when *in situ,* and particularly when somewhat enlarged by imbibition, as they become if the eye be immersed in fluid for awhile, or by the action of its own fluids, they are irregular in outline and overlap each other from distension. They appear to form a single layer of cells. Their size varies much in different animals, the size of the creature being no guide to the size of the cells. They, however, appear to bear some relation to the size of the rods and blood-discs, as these do to each other. They are larger in birds than in mammalia, the largest I ever saw being in the turkey, and in a canary bird (Pls. VII. and VIII.), though these are probably enlarged by endosmose.

The retina is much more easily separated from the vitreous humor after a time than it is immediately after the death of the animal, which may arise from the change these cells undergo.

7. *Vascular layer.*—The retina is a very vascular structure; it is supplied by the central artery of the retina, which almost as soon as it enters the eye divides into two or three branches; these immediately subdivide and form a series of inosculations, the branches pass forwards and form a complete vascular network, until the vessels become capillary, which they do suddenly from vessels of comparatively large size. At first the larger branches are on the inner side of the fibrous layer, but as they pass forwards they gradually penetrate this, some of the branches running parallel with the nerve fibres for a considerable distance (Plate VII., fig. 4); but the smaller branches and capillaries, which form beautiful loops with each other, appear to be exclusively distributed in the vesicular and granular layers, on the outer surface of the fibrous (Plate VIII., fig. 7); none, so far as can be detected, passing into the bacillar layer. Many of them form terminal loops at some distance from the anterior termination of the retina (Pl. VIII., fig. 8). Near the ora serrata there is described to be a circular vessel, into which many others pass; this is regarded by some anatomists as a vein.

It is necessary in injecting these vessels to do so from the ophthalmic or carotid arteries; but the larger branches are so commonly found congested after death, that they may be readily seen, and not unfrequently the smaller ones are so filled with blood, that their minute ramifications may be examined with great facility, particularly where cerebral congestion has existed during life, or immediately after death the animal has been placed with the head in a depending position. (Plate VIII., fig. 7), is taken from the retina of a woman who died of cerebral congestion. In the other eye a small apoplectic clot was found, and several patches of convoluted highly congested vessels.

PUNCTUM CENTRALE RETINÆ, OR YELLOW SPOT OF SOEMMERRING.

I prefer these names to that of foramen given to it by its illustrious discoverer, Thomas Soemmerring.

Exactly in the axis of the eye and one-tenth of an inch external to the entrance of the optic nerve in the living human eye, is a small dark circular spot $\frac{1}{24}$ of an inch large; it is surrounded by a broader yellowish margin, which gradually shades off into the nearly colourless retina, fig. 87.

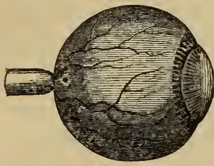

Fig. 87.

The existence of this spot was unknown until Soemmerring discovered it in the eyes of a young man who had a few hours before been drowned in the Rhine. Regarding the dark central spot as an opening, he denominated it the *foramen centrale*, fig. 88. From that time to the present day the greatest interest has attached to this appearance. That a deficiency of structure should exist in that particular spot of a nervous membrane, whose peculiar functions it appears to be to receive the images of objects, where vision is known to be most perfect, could not but excite intense interest and much investigation; yet so fraught with difficulty is the subject, that hardly any two anatomists have agreed as to the precise appearances of the part during life, or as to the structure which causes them, whether regarded by the naked eye or assisted by the microscope. Nor is this disagreement to be wondered at when it is considered that the appearance is almost peculiar to the human eye, that it very soon alters and disappears after death, and the great difficulty there is in procuring recent eyes. I believe indeed the alteration after death is far more speedy than has been supposed possible, and that this has led some of the most accurate and pains-taking anatomists into error respecting it.

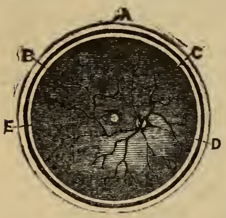

Fig. 88.

I am aware it has been stated that the punctum exists in monkeys, and some reptiles, and from the authority upon which this has been mentioned, an appearance in some creatures must be found; I cannot however but doubt whether this be identical with, or very similar to, the punctum in man. I have dissected the eyes of two species of baboons and three monkeys,

Fig. 87 is a profile view of the eye; the sclerotic, cornea, choroid, ciliary processes, and iris having been removed: the expanse of the retina from the optic nerve to the zone of Zinn, with its blood-vessels and punctum on the outer side of the nerve, are seen; as also the crystalline lens *in situ*.

Fig. 88. Transverse section of posterior half of human eye, seen from the front; A, sclerotic; B, choroid; C, retina; D, optic nerve; E, punctum centrale.

without finding it, and in the alligator, turtle, frog, toad, common snake, chameleon, water newt, and common lizard, I have searched in vain for it. The retina is sometimes thrown into irregular elliptical folds somewhat resembling the appearance of the human punctum as figured and described by Mr. Dalrymple, but in no case have I seen the true characters of the human spot; if therefore there be any such identity, others must have been more fortunate in the specimens examined than I have been.*

Many anatomists, perhaps the majority, following Soemmerring, have described the dark spot as a true aperture, through which the choroid coat is seen; others have asserted there is no aperture, but that at the spot the retina becomes transparent; while others again have thought that one or other of the coats, the inner, middle, or outer, the fibrous, vascular, granular, or bacillar layers of the retina is deficient at the spot; while one of the most recent and able of anatomists, Bowman, though disposed to think there is an opening, is quite unable to feel sure whether there be really an aperture or not,—whether all the tissues or only the outer one be here wanting. Dalrymple, who possessed peculiarly favourable opportunities for obtaining the organ in the most recent state, as he expressly informs us, and who devoted years to its examination, and, therefore, as he said, spoke with great confidence of the correctness of his descriptions, declared that the spot is not circular as described by Soemmerring, and that there is no deficiency of the retina, but that the form is oval, and caused by two minute folds of the retina, which are united at their respective extremities, leaving a depression between them; the length of the folds being one and a half lines, and the breadth nearly one; and that the dark centre and surrounding "*limbus luteus*" result from the folds, which consist of two portions of membrane doubly opaque, and stand out in relief, thus throwing the depression into shade. The dark pigment behind by adding a still greater depth of colour increases the effect of the shadow, fig. 89. Previous observers, including Soemmerring himself, Dalrymple says, having been misled into mistaking post changes for living structures, owing to not having dissected eyes sufficiently soon after death. Yet in a postscript at the end of his volume Dalrymple says he had seen reason to doubt the correctness of the description of which he had spoken at length so confidently of.

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* As most of these creatures which are foreign were obtained from menageries, it is quite possible, though stated by the keepers to have very recently died, had been dead longer than admitted, and too long for any appearance of a punctum to have remained, supposing such to have really existed during life. One monkey, however, was quite warm and free from the rigor mortis, still there was no punctum centrale.

In the Museum of the College of Surgeons there are two preparations of the eye of the chameleon "to show the foramen of Soemmerring," but in them, whatever appearance of the structure there may be is *to the nasal side and a little above* the entrance of the optic nerve, which hardly corresponds with that of the punctum in man. This does not arise from any difference in the relative position of the entrance of the nerves, for, as a reference to the tables of measurement will prove, in both eyes this is to the inner side of the axis of the eye. The preparations 1702, A and B, by Sir E. Home, to show the human punctum as a round hole, are evidently artificial apertures, the result of the strong spirit in which the eyes have been put, an effect which always occurs when the retina is coagulated.

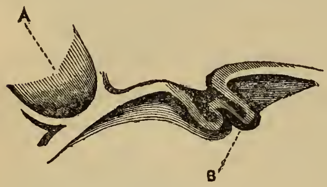

Fig. 89.

In attempting to solve the problem I know that I may expose myself to the charge of presumption, but at the risk of this I will mention what I conceive to be the correct anatomy of this part of the retina. I give however the result of my investigations with great diffidence, and only as what I believe to be correct; but having seen some of the conditions described as the normal living structure actually occur, while examining the part, I think I need not hesitate to declare that these at least are post-mortem changes, and not part of the true living texture.

In cold weather, and in certain bodies, the central dark spot with the surrounding yellow margin may be seen as late as 36 hours after death, but frequently all trace of it is lost in 24, within this it commonly may be seen more or less distinct.* It is always more vivid in the young adult than in

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Fig. 87, enlarged section of retina after Dalrymple; A, optic nerve; B, two folds with central depression, forming the *limbus luteus* and *foramen centrale.*

* In one instance I found it as late as 60 hours after death, but often within 8 hours it has changed in its characters. Why the appearance should remain so much longer in some eyes than in others it is very difficult to say, unless difference in evaporation or exudation may explain it: though as there is a somewhat analogous variation in eyes put up in spirit, in some of which

the old, and better seen on the inner surface of the retina than on the outer. At times the exact appearance represented by Soemmerring is shown, but more commonly the folds and central elongated depression, figured by Dalrymple, are found. Not unfrequently there can be no doubt of an actual foramen, almost always if the eye has been placed in spirit, Goadby's solution, or anything that corrugates the retina; but not unfrequently the folds may be pulled out and the retina be seen continuous between them. Much depends upon the mode and force with which the retina is exposed; but more upon changes which the retina spontaneously undergoes almost immediately after death, and which, in its minute structure, as in a previous page I have said, may be seen to occur in all animals within a few minutes after removal from the body. So soon as the retina begins to be opaque it is evident some alteration in its elements has occurred; besides which the evaporation which ordinarily takes place through the cornea alters the relation of the retina to other tissues, as may imbibition from the vitreous humor, or the fluid the eye is placed in. It is more than probable had Soemmerring not examined the eyes in which he first found the spot almost immediately the body had been taken out of the water, before evaporation had occurred, his discovery would not have been made.

The following description is derived from the examination of the eyes of children born before and at the full term, and either still-born, or such as having shortly died I could procure and examine at once; of eyes procured within four or six hours after death, and particularly of the eyes of two adults, which I have removed for cancerous disease of the appendages affecting the fore part of the eye, and to effectually extirpate which the eye-ball itself had to be removed; preparation for the examination being made before the operations were commenced, so that the almost living eyes were examined, and where certainly the appearances were such as actually existed during life—the retina being transparent.

On making a transverse section of the globe behind the lens,

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the yellow limbus may be seen after the lapse of considerable time, while in others it very quickly disappears, this is hardly satisfactory.

there is seen a minute dense black spot, projecting from the surface of the retina, surrounded by an inner darker yellow margin, and an outer lighter, nearly circular one, which gradually shades off into that of the retina. There is neither aperture nor folds, but presently as the vitreous humor escapes, and the retina loses its support, two folds exactly as figured by Dalrymple are seen to form. They may readily be pulled out, but immediately form again, and always in the same place and direction, and of the same size, with the black punctum in the elongated depression between them; so that there must be some structural cause for their formation. That it does not depend in the adult, as has been suggested, upon the connexion of two of the larger branches of the central artery to the retina at these points is certain, for no branches run in the lines of the folds, nor are there retinal vessels so large in man as in many animals, where the folds do not occur. They appear rather to result from the fibres of the optic nerve dividing, as they pass outwards, and leaving a small space where the punctum is free from the larger filaments, so that when the retina loses the support of the vitreous humor and falls into folds, as it does very soon after the eye has been opened, and is always seen to do after the eye has become flaccid by the aqueous humor having evaporated through the cornea, these folds form the edges where the duplication takes place. Thus I think it may unhesitatingly be said that these plicæ are a post-mortem effect.*

That the appearance of a foramen is equally a post-mortem change I have as little doubt. An opening is at first sought for in vain, but if the eye be placed in spirit, Goadby's solution, water, or left exposed for a time, an aperture more or less circular, and larger or smaller, will be found in the centre of the yellow spot. The best way of developing this is to remove the sclerotic and choroid coats, and place the eye in Goadby's solution diluted by one-half, which beautifully preserves for some days the *macula lutea*. Gradually according to its strength, and consequent contracting effect upon the retina, there is a development of the foramen centrale, resulting, as I believe, like the folds, from the absence at this spot of the mass of nerve-fibres, but the presence of the rods, the granular and true retinal elements, which are more acted upon by the solution than are the fibres, and being weaker give way.

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* I find this idea of the fold being a post-mortem effect has been mentioned by Dr. Knox, and adopted by Bowman.

When the folds are pulled out, or before they form, the dark central spot is seen to project as a minute papilla from the inner surface of the retina, and on the posterior surface is a corresponding, but proportionally less, depression. This is an appearance which becomes more distinct after the retina has remained some hours in Goadby's solution, when an aperture being formed, if a section be viewed in profile it resembles on a microscopic scale the form of a volcano, the aperture being the crater; fig. 19 a, plate 1, shows the projection on the inner surface, and b the smaller depression on the outer surface of a section in profile through this spot, magnified 60 times, after four days in the solution.

If the inner surface of the fresh retina be examined with the 2 or 1 inch object-glass, there is seen an irregular circle of a canary yellow or pale lemon colour, with a dark irregularly circular spot, which breaks up into detached portions, looking like patches of the black matter of the choroid coat upon the inner surface of the retina, which here appears slightly elevated as though a little thicker than the rest of it, and there is clearly a continuity of the nervous structure over the inner surface of its expanse.

With the ½-inch glass the same structure is seen, but the yellow tinge now appears to result from the deeper colour at the spot of the irregular granular cells, of which the whole inner part of the retina consists; while the dark central part clearly is made up of an aggregation of the minute colouring cells of the choroid coat; the appearance of a distinct spot is however much less characteristic under the half-inch lens than it is to the naked eye, for the yellow appearance melts into the surrounding retina, and the dark central foraminal appearance is shown to be a patch of the choroidal colouring globules, on the inner surface of the nervous tissue, hence it is difficult instantly to recognise the exact spot either by reflected or transmitted light.

With the ¼ and still better the ⅛ object-glass when the part is gently spread out, and very carefully and lightly pressed upon with the cover (for the whole retina is too thick without this), the dark spot is resolved into distinct minute choroidal colouring globules, which, as I have stated when speaking of the choroid coat, in thin layers appear of a yellow or faint lemon colour. (Plate I., fig. 17 and 18). Thus I believe the yellow colour of the punctum results from an intermingling of these minute choroidal particles with the granular cells, rather than a positive yellow colour of these cells themselves, as has been asserted; while the central spot is clearly due to a denser, more connected patch, of choroidal globules, and which, by a little pressure and teazing out, may be resolved into the separate globules, lying upon (within) the granular and cerebral cells of the retina, which are as thick and numerous at this spot as in any other part of its expanse. I believe also that the rods are equally continuous on the outer surface, so that the appearance of the *punctum centrale* and surrounding *limbus luteus* depends upon the addition of the minute choroidal colouring globules to the normal retinal elements; diffused more or less in the yellow and lemon margin, collected into a mass in the dark central spot.

Of the use of this peculiar spot it is very difficult to offer any satisfactory opinion;—wherein it differs in function from other portions of the retina, or why it should be (at any rate so distinctly) confined to man. That vision is most acute in the axis of the eye, in which it is placed, all persons seem agreed, but that this depends upon a specific and peculiar arrangement in the part itself, is at least doubtful, for there is no abrupt transition from acute to imperfect sight, nor any noticeable change which would correspond with the precise boundary of the spot in man, which there ought to be, supposing there is here a well-defined structure peculiarly endowed with visual perception; and there is no reason to think in respect of acute vision the axis of his eye differs from that of most other animals where no corresponding central appearance is to be found.

In the fœtus, even up to the period of birth, the punctum is much less distinct than in after-life; there is no regular circular limbus, but instead the retina at this part is more or less bulging, with irregular quadrilateral depressions uniting in a central deeper one, in which is placed a considerable blood-vessel, which there divides into branches, generally four. These run in the radiatory retinal folds.

On the whole I incline to regard this much-debated spot as a vestigiform remains of the spot where a large blood-vessel has passed through the retina in the development of the eye and carried with it some of the choroidal colouring-matter. (I forgot to say, that in the course of the blood-vessels in the adult retina, the colouring particles are more numerous and more prolonged than in the intermediate places), and which in after life ceases to exist, the retina being then exclusively supplied with vessels from the central artery of the optic nerve,—the direction of the folds of Dalrymple deriving some explanation from this idea, or it may be an undeveloped analogue of the marsupium in birds, but if so, why it should not be generally distributed it would be difficult to say.

The more acute visual perception which the axis of the eye enjoys over other parts of the retina, I should rather attribute to the more perfect development of the true retinal elements at the centre of the eye, from whence there is a gradual diminution in the thickness of the texture, and consequently in the size of these elements, than to any other cause, acuteness of the different parts of the organ corresponding with the greater or less development of its tissue. It may also possibly happen that the presence of the minute choroidal pigment-cells among the retinal elements may conduce towards acuteness and distinctness of vision, by destroying the luminous spectrum more instantaneously than is effected by the pigment when placed solely in the choroid behind the retina.

I append the size of the rods and granular cells in some mammalia; and of the rods, cones, and bulbs in some birds, reptiles, and fish, in parts of an English inch. I would, however, wish the measurements to be regarded as no more than approximations to the absolute size of these bodies, which certainly differs in different parts of the same retina.

Fig. 16, Plate I., is a section of the left eye of a woman made seventeen hours after death, the drawing being made an hour after the section had been made, when some of the vitreous humor had escaped and the retina at the central spot became enclosed in elliptical folds as represented by Dalrymple.

MAMMALIA.

	RODS.		GRANULAR CELLS.
	Long.	Wide.	
Man	1-2700 to 1-1800	1-10,000 to 1-6,500	1-16,000 to 1-5000
Ditto, at yellow spot	1-1800	1-6,500	
Pig, No. 1	1-2700 to 1-1800	1-10,000 to 1-7,200	1-16,000 to 1-5000
Ditto, No. 2	1-2000 to 1-1500	1-10,000 to 1-7,000	1-16,000 to 1-5000
Dog	1-2500 to 1-1375	1-12,000 to 1-6,000	1-16,000 to 1-5000
(Small spaniel)	most about 1-1800	most about 1-7,000	
Cat	1-2700 to 1-1800	1-16,000 to 1,10,750	1-16,000 to 1-6000
Horse	1-1800 to 1-1250	1-10,800 to 1-6,000	1-16,000 to 1-4000
Bullock	1-2000 to 1-1400	1-10,000 to 1-5,500	1-16,000 to 1-4000
Sheep	1-2500 to 1-1550	1-10,000 to 1-7,000	1-16,000 to 1-5000
Rat	1-2700 to 1-1800	1-14,000 to 1-10,000	1-12,500 to 1-5500
Mouse (both the common house and short-tailed field)	1-2700 to 1-1800	1-10,800	1-16,000 to 1-6500
Hare	1-2700 to 1-1800	1-10,800	1-16,000 to 1-6000
Rabbit	1-2700 to 1-1800	1-10,800	1-16,000 to 1-5500
Hedgehog	1-2700 to 1-1800	1-10,800	1-16,000 to 1-6000
Mole	1-3000	1-12,000	1-20,000 to 1-8000

BIRDS.

	RODS.		COLOURED GLOBULES.		
	Long.	Wide.	Ruby.	Yellow.	
Turkey—					
Cylindrical rods .	1-770 to 1-650	1-11,000 to 1-7000	1-7000 to 1-4000	1-16,000 to 1-5000	Yellow globules are three times as numerous as the ruby; some few are as large, but on the whole they are considerably less, some being very small.
Conoidal rods .	1-770 to 1-650	1-4,000 to 1-2000			
Common Fowl—					
Cylindrical rods .	1-770 to 1-650	1-11,000 to 1-7000	1-7000 to 1-4000	1-16,000 to 1-5000	As above.
Conoidal rods .	1-770 to 1-650	1-4,000 to 1-2000			
Guinea Fowl—					
Cylindrical rods .	1-750 to 1-650	1-11,000 to 1-7000	Ditto	Ditto	
Conoidal rods .	1-750 to 1-650	1-4,000 to 1-2000			
Sparrow and Canary Bird . . .	Ditto	Ditto	Ditto	Ditto	
Domestic Duck—					
Most of rods conoidal . .	1-770 to 1-675	1-5,400 to 1-4000	Ditto	Ditto	
Domestic Goose—					
Some conoidal, but more cylindrical, rods . .	1-1100 to 1-775	1-5,500	Ditto	Ditto	
Domestic Swan—					
Most conoidal rods . .	1-850 to 1-750	1-6,000 to 1-4000	Ditto	Ditto	
Ovoid bodies .	1-1800	1-2,700			

REPTILES.

	RODS.		COLOURED GLOBULES.	
	Long.	Wide.	Ruby.	Yellow.
Turtle (green)—				
Long cylindrical rods	1-900 to 1-675	1-11,000	1-5500 to 1-3000	1-10,000 to 1-5000
Short cylindrical rods	1-1365 to 1-1100	1-5500		
Conoidal rods . .	1-700 to 1-600	1-2700		
Globular or ovoid bodies, bulbs or cones . . .	1-1800 to 1-1350	1-4000 to 1-2000	Some, however, of both ruby and yellow globules are so small as to be hardly perceptible; with 1-8 object glass; not more than 1-200,000.	
Common Frog—	1-600 to 1-360	1-5000 to 1-2500		
Majority of rods, about	1-500			
Toad	1-900 to 1-700	1-4000 to 1-3000		
Alligator . . .	1-900 to 1-600	1-5500 to 1-4000		
Very few rods so long as . . .	1-600			
Chameleon . . .	1-1365 to 1-1050	1-5500		

FISH.

	RODS.		BULBOUS OR CONOIDAL BODIES.	
	Long.	Wide.	Long.	Wide.
Cod	1-1050	1-4700	1-1050	1-2500 to 1-1700
Haddock	1-1050	1-4700	1-1050	1-2500 to 1-1700
Whiting	1-1500 to 1-1100	1-11,000	1-1000 to 1-800*	1-1800
Billett	. . .	. . .	1-900 to 1-700	1-2500 to 1-7000
Sand Dab	1-1800 to 1-1360	1-16,000 to 1-11,000	1-1800 to 1-1360†	1-2700
Little Viper Fish	1-1040 to 1-900	1-16,000 to 1-11,000	1-1040 to 1-900	1-4000 to 1-2000
Mackerel	. . .	. . .	1-900	1-1360
Carp (golden)	1-1360 to 1-1080	1-11,000 to 1-5500	1-1800 to 1-1050	1-2700 to 1-1800
Greyling	1-1000 to 1-900	1-16,000	1-900	1-2700 to 1-1850
Trout	1-1000	1-16,000	1-900	1-2700 to 1-1800
Dace	1-1000	1-16,000	1-900	1-2700 to 1-1800
Perch	1-1100 to 1-620	1-11,000 to 1-5500	Cones in fish examined very few and imperfect.	
Most	1-1100			
Eel	1-2700 to 1-1800	1-16,000 to 1-11,000	1-2700 to 1-1800	1-5500.

* Conical legs and bulb of equal length.

† Of which the conical legs form rather more than one-half.

HUMORS OF THE EYE.

To the softer and fluid portions which occupy and distend the cavities formed by the solid tissues the term humors has for ages been applied. It is neither appropriate nor exact, for the most important of the three—the *crystalline lens*—is a solid, and the other two—the *vitreous* and *aqueous* humors—have nothing more than their fluidity to justify the appellation. An able writer who has taken objection to the term has proposed to substitute that of "refractive or dioptric media" as more expressive of their function. This term, however, is not so free from objection as he appears to imagine, inasmuch as the cornea is undoubtedly one of the most important of the refracting powers of the eye, and yet it forms one of the investing solid coats and not one of the contained humors.

HYALOID OR VITREOUS HUMOR.

Of the three it is of comparatively little importance which is first described: perhaps on the whole it is more convenient to commence with the vitreous, which is by far the largest of them, filling, in man and the higher mammalia, from three-fourths to four-fifths of the whole cavity of the globe; in the lower mammalia, reptiles, and fish, in consequence of the flattened form of the globe and the large size of the lens, and in birds of the large aqueous chamber it occupies less space than it does in mammalia.

The vitreous humor is so transparent that when placed in pure water it is with difficulty seen, its name well denotes its appearance. Though apparently of the consistency of thin jelly, its density is but little more than that of the aqueous humor, or of water, as is proved by its specific gravity, and by its refractive power. According to Berzelius it consists of—

Water	98·40
Albumen	0·16
Chloride of sodium with a little extractive matter	1·42
A substance soluble in water . . .	0·02
	100

Its refractive power as estimated by Brewster is 1,3394.

It fills up the whole of the cup-like cavities of the retina, choroid, and sclerotic, which are superimposed upon and co-extensive with it. In fish, reptiles, birds, and the lower mammalia its shape is that of a flattened spheroid; in the higher mammalia it is more spherical; and in man, posteriorly and laterally, as far as the base of the ciliary body it approximates very nearly to a sphere: at this point it is flattened anteriorly, and in its middle there is a deep depression, in which is partially imbedded the crystalline lens. The retina in its whole extent, as far as the ora serrata, lies smoothly upon the vitreous humor, to which it is connected by the layer of extremely delicate cells before described. It is very difficult to determine whether they belong to the retina or the vitreous body (plate 7, fig. 1). This connexion I believe to be organic, and not merely a superposition of the retina, as has been commonly described. True if the eye has been placed in water, or not examined until some hours after death, this is the case. There is no connexion then, the retina simply lies upon the vitreous body, the delicate cells have imbibed water and become much distended, and the attachment is destroyed; but if the structure be examined immediately an animal is destroyed, and while the retina is perfectly transparent, it will be found that it adheres with considerable tenacity to the hyaloid membrane. At the entrance of the optic nerve the connexion is more evident, at this point, during development, a considerable blood-vessel passes from the central artery of the retina through the vitreous humor to the posterior capsule of the lens, it even conveys red blood at the period of birth, and in some animals for some time after (plate 3, fig. 7). It is probably some slight remains of this, and the larger size of the cells of the hyaloid in its course, that have led some anatomists to the idea of there being a central canal or cavity in this body. I have also fancied I have found a rather closer connexion of the retina and hyaloid at the yellow spot than in other situations, arising probably also from the same cause,—a blood-vessel or vessels having there entered the vitreous body. In after-life no

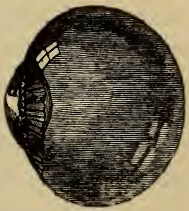

Fig. 90.

Fig. 90 shows the vitreous humor with the lens imbedded in it, surrounded by the zone of Zinn and the canal of Petit. See also plate 3, fig. 7.

vessels or nerves have been detected in the vitreous humor. It derives its nutriment through the retina and, as many think, the ciliary processes also. The vitreous body consists of a mass of fluid, in physical and chemical characters very like the aqueous humor, and of an exceedingly delicate membrane which is structureless or nearly so, for under a high magnifying power nothing more than a finely granular surface with a few nuclei can be seen. This membrane is commonly described as cellular, containing the fluid in its interstices, hence the form and apparent solidity of the whole mass. This account I believe to be substantially true, for though it is impossible to demonstrate these cells in the recent eye, many facts tend to corroborate this opinion. If the vitreous humor be suspended the fluid drains out with a rapidity in proportion to the number of punctures made in it, leaving a small white solid portion. So also if the body be placed in alcohol, diluted acids, or solution of bichloride of mercury, or other fluids, especially if boiled in water, the fluid escapes, and an opaque white structureless membrane is left.

It has been attempted to show that the hyaloid membrane consists of a series of layers superimposed upon each other, being less closely approximated towards the centre than towards the circumference. Brucke thought this structure was made evident by immersing the vitreous body in a solution of acetate of lead; and by the size, shape, and direction, in which morsels are detached from the frozen vitreous body. Hannover appears, from analogous experiments (immersion in chromic acid), to have supposed that the hyaloid membrane, at least in man, consists of segments radiating like those of an orange towards the axis, but not actually reaching it. Bowman has repeated these experiments and made many others, which, though at first apparently confirming the statement of Brucke, led him in the sequel to conclude, as I feel sure is the case, that those appearances are deceptive, depending upon physical and accidental causes, and do not show any particular structure.

I have repeated these experiments, and made many others upon the eyes of various animals, more particularly those of the ox and sheep, with the result of feeling satisfied that Brucke and Hannover have been deceived in their investigations. I have placed eyes unopened, the entire vitreous body with only the crystalline lens attached, and the vitreous body cut up into various sections, in solutions of acetate of lead, and allowed them to remain for varying periods, from a few days to upwards of two years. In all a white deposit occurred; in the entire vitreous humor, in lines, more or less concentric with the retina and posterior surface of the lens, and becoming less perfect towards the centre of the body, at which none were found;—thus, supposing the portions of carbonate of lead were deposited upon the hyaloid membrane only, confirming the idea of Brucke, that there is a central cavity surrounded by concentric layers; but when those vitreous bodies which had been cut into sections were examined, it was found that the opaque layers were as various as possible, and that they could be made to take any direction, according to the manner in which the portions were deposited in the solution, and the strength of the solution. In fact, the deposit appears to be a mere chemical effect. The true reason of the outer layers being more distinct than the inner arises not from difference in the texture of the hyaloid body, but from the fact of its central parts not being so well brought into contact with the soluble salt, for as the insoluble carbonate is deposited upon the outer portion it prevents a free contact with the inner; or the entire acetate is decomposed and precipitated upon the outer surface; and if a stronger solution be employed, the only effect is that the outer incrustation is more rapid, dense, and impermeable, while the central portion is decomposed, thus giving rise to Brucke's notion of a central cavity.

The idea occurred to me that if I could saturate the hyaloid body with some soluble and transparent salt which could then be decomposed and fixed I might succeed better, I accordingly immersed several vitreous bodies, whole and in sections, in solutions of hydriodate of potass, and subsequently put them into solutions of acetate of lead. I got beautiful deposits of iodurate of lead, but merely upon, or slightly within, the exposed surfaces in varying lines according to the sections and direction of contact. Other vitreous bodies I saturated with hydriodate of potash, then placed them in a solution of starch and set free the iodine, they became imbued with a blue colour more or less decided, but there was nothing to prove structural anatomy. Chromic acid, tannic acid, and simple colouring agents, as cochineal and turmeric, are not more useful; and I feel convinced that the chipping portions off a frozen vitreous body, or the fragments into which it breaks up on being brought into a warm temperature, are mere physical occurrences, and do not point out the size or arrangement of cells. That under some circumstances an appearance of a central canal with filaments more or less distinct may exist is not improbable, for it appears certain development takes place from the centre, and that during this there is a canal through which vessels pass and radiate, so that vestiges of this may remain more or less distinct.

The crystalline lens is imbedded in a depression in the centre of the flattened anterior surface of the hyaloid body (figs. 83, 84, and 90. Plate III., fig. 7), in which it has been commonly described as being retained by the hyaloid membrane splitting at the edge of the lens, one portion passing behind to complete the entirety of the membrane, while another passes before the lens, commingling with its capsule, and thus holding it *in situ;* the lens thus being enclosed between two layers of the hyaloid membrane. These, as they diverge at the edge of it to pass upon its respective surfaces, were thought to leave a small triangular space, the base being formed by the edge of the lens, as was first described by Petit; but there is reason to consider this is incorrect, as I shall presently point out.

Zonula Zinnii.—Surrounding the lens there is the appearance of a radiated disc. fig. 88. This arises from the hyaloid membrane being thrown into a series of folds, which in number, form, and size are the counterparts of the ciliary processes, and with which they are very intimately connected, the elevations and intervening folds being mutually received into each other. This structure was particularly described by Zinn, and constitutes the zone of Zinn or the ciliary processes of the hyaloid membrane. However carefully the ciliary processes are removed some portion of pigment, more or less considerable, is always left upon this structure, but by immersion in water for some hours and the use of a camel-hair pencil it may be entirely removed, when the beautiful series of folds are seen to consist of a membrane far more dense and hard than the other portions of the hyaloid. Hence, although described by Zinn, and since his time almost universally so until very recently, as folds of the hyaloid, in all probability they really belong to a different structure — the suspensory ligament of the lens. The outer or external margin of these folds exactly corresponds with the bases of the ciliary processes, where they are the deepest and most distinct. The inner or internal however does not terminate abruptly at the apices of the processes, but is prolonged somewhat upon the anterior margin of the lens, being much more perceptible when put upon the stretch, and somewhat greater in some eyes than in others of the same species of animal. This has given rise, I think, to the erroneous description by some anatomists of the ciliary processes themselves being prolonged upon and attached to the edge of the lens, which they are not.

Suspensory ligament of the lens.—Though in describing this structure it will be necessary to refer to the lens and its capsule which have not yet been described, it will be more convenient to take it first. The recognition of it as a distinct structure is of comparatively very recent date, for though many years ago the engravers of Sir E. Home's plates very accurately figured this structure in the ox, well showing its elastic character, yet Home's description of its texture and functions were so obviously erroneous and fanciful, resulting from a foregone conclusion to prove its muscularity, that little attention was given to the fact of the presence of any distinct structure existing where he accurately described this to be.* The name by which it is now known was given to it by Retzius. It has also been described by Bowman, Kölliker, and others. It is a very delicate and highly transparent structure, and being most intimately connected with other tissues more evident than it, there is no wonder it should for long have escaped recognition, and that even now observers should differ somewhat in their accounts of it. It lies between the ciliary processes and the vitreous humor, forming as has just been mentioned the zonula Zinnii. It may be detected in man and in all the higher animals, but I think it is stronger and more distinct in the horse than in any other creature I have examined, where its presence is easily enough ascertained. It extends from the *ora serrata* of the retina to the edge of the anterior capsule of the crystalline lens, but might with, perhaps, equal correctness be described as arising from the anterior capsule of the lens and passing backwards to the retina, as proceeding from this point to the lens as it usually is.

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* Home's Lectures on Comparative Anatomy, vol. iii.

Though the true nervous structure of the retina ends at the serrated line, behind the base of the ciliary processes where the choroidal structure appears to come into contact with the hyaloid body, there is continued from the edge of the retina an exceedingly delicate granular reticulated tissue, which after immersion of the eye for some days in spirit, and still better in Goadby's solution, becomes much more opaque and distinct, assuming then a nearer approximation in appearance to areolar connective tissue, in which a good number of choroidal cells with but little pigment are mingled. It adheres very closely to the ciliary processes, and is lost upon them, while on its inner surface, and confounded with the hyaloid membrane, is a dense, hard, highly elastic structureless membrane, which, at the apices of the ciliary processes, as I believe, splits into two layers, one, an extremely thin one, passing to the posterior capsule of the lens upon or near the margin of which it is lost (fig. 84); or it is there confounded with the hyaloid membrane; for so delicate is it, and so closely are these parts connected, that it is impossible to say if this be so, and the hyaloid membrane be continued uninterruptedly behind the lens, or whether the membrane be imperfect and only completed by the capsule of the lens, the whole of the suspensory ligament passing in the anterior wall, as Bowman and others think. The former arrangement is however I think more consistent with my examination of the part in the horse, is more consistent with analogy, and also more nearly agrees with the idea so long and generally entertained by anatomists of the splitting of the hyaloid membrane itself to form the two walls of Petit's canal. The anterior (or entire) portion is far the stronger, it leaves the hyaloid body, passing inwards and forwards it reaches the anterior capsule of the lens a little beyond the edge of it, where it becomes confounded and identified with the capsule, which is thus materially strengthened, while it is retained by this elastic brace *in situ*. This portion is not perfectly smooth, but retains, as it passes over the margin of the lens, a remnant of the folded character it had while in connexion with the ciliary processes, which give to it something of a striated character, and has probably led to its being described as a fibrous structure, when in reality these are mere foldings of a perfectly homogeneous structureless membrane, which more nearly resembles and, indeed, is probably identical with the capsule of the lens, and the inner elastic layer of the cornea, than anything else. It is like them highly elastic, curls up when divided in a direction contrary to the curve in which it is laid down; it is strong, hard, and dense, but brittle and easily broken, and like them it is unaffected by spirit, acids, or boiling water. That this structure plays an important part in preserving the lens *in situ*, its position and connexion render certain, but it is probably not less certain that its elasticity is an important element in the optical changes necessary for the adjustment of the eye to vision at different distances; for though its property may be more of a physical than an active vital one, still when changes in the shape, position, or relation of the lens to other parts of the eye have been made by other means, this elasticity may be a most important means for restoring the parts to their normal quiescent condition, thus supplying an explanation of a difficulty which many learned opticians have long felt exists in understanding the manner in which the eye so successfully overcomes the aberration of parallax: they believing some means of altering the condition of the lens must exist near to the lens itself, while the anatomist could detect no structure which he could suppose capable of effecting this. Kölliker says that from the ora serrata to the canal of Petit no hyaloid membrane exists; he therefore describes these structures as modifications of the hyaloid membrane and the cells of the choroid. I should rather incline to consider the outer layer as a prolongation and modification, particularly of the pigment structure, of the choroid, and the inner stronger elastic layer as a portion of the anterior capsule of the lens, prolonged backward, so as to fix it firmly *in situ*. It is the first layer that doubtless has led several anatomists to suppose the retina itself is prolonged to the lens.

Canal of Petit at the margin of the lens is a very narrow canal, formed, anteriorly, by the portion of suspensory ligament passing to the anterior capsule of the lens, posteriorly by that portion of the ligament, or the hyaloid membrane itself, going to the posterior capsule of the lens, the apex being the spot where these separate, and the base that narrow part of the margin of the lens which is left free with its capsule to project into this space between the two walls, fig. 84. These walls in a normal condition are probably in contact, or at most only separated by a very minute quantity of serous fluid, but they may easily be separated from each other by the introduction of air, coloured sise or fluids, or of mercury; when surrounding the lens is seen a sacculated ring, which was first described by PETIT, and hence called after him, figs. 88 and 90. The syringe or blowpipe may be introduced either through the vitreous humor into the posterior wall, or by the margin of the lens, into the anterior. When distended with air or mercury, and the eye is placed in water, it forms a pretty and distinct object, but the walls soon give way. It is by so doing that the two walls of the canal, the sacculated character of the anterior, and the free margin of the lens are best seen. The sacculated character of the canal arises from slight filaments passing between the two walls, and also from some portions passing direct to the margin of the lens rather than beyond it.

To see the suspensory ligament of the lens and Petit's canal properly, the sclerotic should be carefully cut through about two lines from the cornea; this must be gently removed, then the choroid, iris, and ciliary processes should be taken away, leaving the zonula of Zinn entire with the lens *in situ.*

CRYSTALLINE LENS.

The Lens, as its name implies, is the most important portion of the dioptical ocular apparatus. It is at the same time the most perfect of its kind in the world. It has hitherto (and probably will continue so to do) defied the efforts of human ingenuity to imitate. Hence, while its importance in health, the great changes which it undergoes in disease, and the skill and knowledge requisite for its treatment and removal, have always rendered it an object of great interest to the anatomist and surgeon—its perfect action in converging the rays of light to a focus upon the retina, so as practically, if not absolutely, to overcome the aberration of sphericity, has caused its form, structure, and density to be matters of the closest investigation and calculation by opticians and mathematicians. The difficulties of the inquiry have been at least equal to their importance, so that as much, if not more, controversy and difference of opinion have existed as to the structure of the crystalline lens, as of any part of the eye.

As is well known, the lens is partially imbedded in the anterior surface of the vitreous humor, where it is held *in situ* by the elastic suspensory ligament. It lies immediately behind the iris at the juncture of the anterior with the middle third of the globe. In man, mammalia, birds, and reptiles it is a double convex lens, of which the posterior surface is considerably the more convex, particularly in the two former classes. To the exact proportions which the curves of the two surfaces bear to each other, opticians have necessarily attached great importance. Many experiments have been made, and far more numerous elaborate calculations entered upon for determining it. Such inquiries are perhaps of more interest and importance to the optician than to the anatomist and surgeon; and from the nature and structure of the lens, when made experimentally, are not susceptible of absolute accuracy; for it is almost impossible to measure, with mathematical precision, the curves of a small, delicate, yielding substance, like the lens. Nor is this question of primary importance; for, it is beyond doubt, that not only do the two surfaces differ somewhat in different individuals, but they vary very much in the same person at different periods of life. There is a gradual flattening of the surfaces, with an increasing density of the substance of the lens, as age advances. In the new-born infant the lens is as soft as rather thin jelly; in old age as firm as suet. In infancy the lens is comparatively convex to its form in the aged. Fig. 1 (plate vi.) shows their varying forms—*a* in infancy, *b* in the adult, *c* in old age. However, notwithstanding these difficulties and changes, much interest and importance is attached to the determining, with as much precision as the nature of the case admits of, the form of the curves and the density of the material forming the lens. So far as I am aware, Petit, in the earlier half of the last century, is the only person who has carefully and extensively experimentally investigated the first of these problems; for though many persons have since then, and particularly Dr. Porterfield and Dr. Thomas Young, written elaborately on the subject, it would appear their investigations have rather been theoretical and calculative, based upon Petit's measurements, than upon original experiment, except perhaps Dr. Young; and from his statement I am unable to determine whether he exclusively depended upon Petit's figures or not.* According to Petit the diameter of the lens is about four or four and a half lines, and its axis two lines. "The diameter of the sphere of which the anterior segment is a part being from six to twelve lines, but most commonly about seven and a quarter or eight lines; whereas the diameter of the sphere of which its posterior segment is a part is commonly only about five or six lines."† According to the calculations of Dr. Young the radius of the anterior surface of the lens is ·30, of the posterior surface ·22 of an inch.

The following table will show the result of my measurements of the lenses of different creatures. I give them only as approximations to accuracy; for though I have taken every care that I could exercise to ensure as much correctness as possible, as I before said, I believe it to be impossible to measure any single lens with absolute precision; the result of the whole must be looked at, and this, I believe, will not be far from the truth. One proof I think of the general correctness of the measurements, is the curious fact shown by them, that the proportion of the curve of the posterior surface to the diameter of the lens, is far more uniform than that of the anterior surface. The radius of the posterior curve differs very little in any of the creatures from the half of the diameter of the lens, so that in fact the posterior surface of the lens is nearly, but not absolutely, a hemisphere, while the anterior is a segment of a much larger sphere, it being on this surface that the variations at different ages in the individual, and different creatures, take place much more than in the posterior surface of the lens—a point of no little importance to the ophthalmic surgeon. The table also shows, that as we descend from man to fish, there is a gradual increase in the convexity of the lens until in them it is a true sphere, and that this increase in the sphericity is not necessarily accompanied by an increase in the density of the lens, as a reference to the table of the specific gravities of the lens will show. The measurements are given in parts of an English inch.

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* "Miscellaneous Works of Dr. Thomas Young." By Dr. Peacock. Vol. i. Nos. 1, 2.

† Porterfield's "Treatise on the Eye," vol. i. p. 231.

HUMAN CRYSTALLINE LENS.

	Diameter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
1. Large-sized adult male, one eye . . .	·33	·21	·1697	·2101
2, 3. Adult male (æt. 25), died after accident, both eyes exactly alike	·36	·18	·2022	·2664
4, 5. Adult female (æt. 40), died from heart disease and albuminuria, both eyes exactly alike	·36	·20	·1896	·2664
6. Adult male (æt. about 50), one eye . .	·36	·22	—	—
7. Male (æt. 65), died from softening of brain, one eye	·36	·21	—	—
8. Small female, one eye	·31	.20	—	—
Average diameter of eight eyes . ·3500				
Average axis of eight eyes . . ·2000				
Average radius of posterior curve of lens of five eyes . . . ·1906				
Average radius of anterior curve of lens of five eyes . . . ·2551				
Six months' fœtus	·25	·14	—	—
Nos. 4 and 5 were immersed for a few minutes in water at 160° F., the measurements were altered to—				
In No. 4	·32	·22	·1614	·2000
No. 5	·30	·22	·1503	·1806

MONKEY.

1. Probably lens somewhat too convex from being a short time in dilute spirit . .	·32	·24	—	—
2. Ditto ditto . .	·32	·20	—	—

PIG.

1. Large, more than twelve months old . .	·56	·44	—	—
2. Smaller, about four months old . . .	·52	·32	—	—
3. Of small breed	·40	·32	·2011	·2128
4. Ditto	·40	·32	·2011	·2128
Average diameter of lens . . ·4700				
Average axis of lens . . . ·3500				

CAT.

Adult male cat just killed, both eyes exactly alike	·4700	·3200	·2417	·2720

BULLOCK.

	Dia-meter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
1.	·74	·50	—	—
2.	·74	·50	—	—
3.	·72	·50	—	—
4.	·72	·50	—	—
5.	·72	·50	—	—
6.	·69	·47	·3483	·4350
7.	·69	·47	·3483	·4350
Average diameter of lens . . ·7171				
Average axis of lens . . . ·4914				
Average radius of posterior curve of lens . . . . . ·3483				
Average radius of anterior curve of lens . . . . . ·4350				

SHEEP.

	Dia-meter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
1.	·57	·40	·2892	·3338
2.	·57	·40	·2892	·3338
3.	·57	·40	·2892	·3338
4.	·57	·40	·2892	·3338
5.	·60	·40	·3075	·3612
6.	·58	·40	·2952	·3428
Average diameter of lens . . ·5766				
Average axis of lens . . . ·4000				
Average radius of posterior curve ·2932				
Average radius of anterior curve ·3398				

HARE AND RABBIT.

	Dia-meter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
1. Hare	·46	·37	·2309	·2453
2. Ditto	·46	·37	·2309	·2453
3. Ditto, very large	·50	·38	—	—
4. Rabbit, rather small	·43	·32	·2184	·2350
5. Ditto, ditto	·42	·32	·2125	·2275
Average diameter of lens . . ·4540				
Average axis of lens . . . ·3520				
Average radius of posterior curve ·2231				
Average radius of anterior curve ·2382				

BIRDS.—COMMON FOWL AND DUCK.

	Dia-meter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
1. Very large cock, both eyes alike	·32	·22	·1634	·1872
2. Ditto, ditto	·27	·21	·1350	·1539
3. Smaller cock, ditto	·28	·18	—	—
4. Hen, ditto	·26	·17	·1345	·1557
5. Duck, ditto	·32	·24	—	—
6. Ditto, ditto	·26	·20	·1304	·1456
Average diameter of lens . ·3850				
Average axis of lens . . . ·2033				
Average radius of posterior curve ·1408				
Average radius of anterior curve ·1606				
(Twelve lenses measured.)				
The lens of No. 2 was immersed in water at 160° F.	·26	·23	·1313	·1456

REPTILES.

	Diameter.	Axis.	Radius of posterior curve.	Radius of anterior curve.
Alligator, both eyes alike	·48	·40	—	—
Small frog, ditto	·20	·16	·0502	·0532

FISH.

Cod, large, both eyes	·58	·58	Equal.
Haddock, ditto	·53	·53	Ditto.
Halibut, left eye	·52	·52	Ditto.
Ditto, right eye	·50	·50	Ditto.
In this fish the right eye, in all its measurements, was smaller than the left, and it is a curious fact, that though the right lens was smaller than the left, yet its specific gravity was somewhat greater.			

The axis of the lens is a line drawn from the centre of its anterior surface to that of its posterior. This in the human adult measures from the ·18 to ·22 of an inch. The diameter is a line drawn across from one point of the margin to the opposite, so as to divide the junction of the two surfaces. It measures from ·31 to ·36 of an inch in every direction, so that the lens is circular in its outline. This it is commonly regarded as being, not only in man, but in all animals. I am not, however, quite certain that some, which have the pupillary aperture very much extended horizontally, have not the lens also slightly broader in the horizontal than in the vertical direction. I have thought the measurements in some instances have been so. The axis of the lens is supposed to correspond exactly with the centre of the pupil. Now, as this is in most persons somewhat, and in some considerably, inclined towards the nasal side of the eye, were it so the axis of the lens would not correspond with that of the eye-ball, but lie to its inner side. It is, however, far more probable that the axes of the lens and of the eye-ball exactly correspond.

The lens consists of its proper structure and its containing capsule. These are of totally dissimilar tissues.

The recent lens itself is to the naked eye a perfectly homogeneous substance, clear as crystal, hence its name—crystalline lens. It has a gradually increasing density from its margin to its centre; but in the infant the whole lens is more uniformly soft, and in the octogenarian more uniformly hard, than it is in the vigorous adult. This variation in density constitutes one of the most admirable provisions in the whole animal economy, as has already been explained at page 73 and elsewhere; were it not for this arrangement either the vision would have been very imperfect, or a much more complicated apparatus, as in the lens of the telescope and microscope, would have been essential.

It is curious to note the very exaggerated notions which formerly were entertained as to the great density of the crystalline lens. Thus Maitrejean concluded, from some experiments he made, that it is heavier than sulphuric acid or aqua fortis. But Dr. Porterfield informs us that Dr. Robertson weighed five crystalline humors of the oxen's eye and three of the sheep's, and found the mean of the oxen 1·1134, of the sheep 1·1033, and of the eight to be 1·1083, from which he presumes that of the human to be the same. Chevenix states the sp. gr. of the human lens to be 1·079; of the sheep 1·180.* These experiments are too few in number to be relied upon. To determine the density of the lens in various creatures I have taken the specific gravity of a great number. The following tables will perhaps be thought sufficiently extensive to enable a fair estimate to be arrived at; more especially as these figures are not like those in the former tables. They may be taken without hesitation as correct, there being no difficulty in taking the sp. gr. of the lens. It will be seen that Porterfield in his conjecture was not far wrong as to the human lens, and that the average weight of Dr. Robertson and mine, for bullock and sheep, wonderfully correspond, considering the individual lenses do not weigh alike, a fact which I was not aware of until after all my experiments had been made. The tables show that, while there is a general agreement in the sp. gr. of the lens in animals of the same genus, there is a perceptible individual difference, which age alone will not entirely account for. In some few instances I have found the curious fact, that the sp. gr. of the two lenses, from the same creature, are not identical,† and the still more interesting one, that in such cases the size of the denser lens has been somewhat less than that of the lighter. This was well marked in the halibut, Nos. 6 and 7. They also show that in true land-creatures the sp. gr. of the lens is less than it is in water-creatures—the density of the lens of the duck, for instance, is decidedly greater than that of the common fowl—while the difference in that of the fish and the bullock and pig is very marked. The first table also shows that the lens is the densest of all the ocular tissues—and particularly so in the fish—where, from the density of the element from which it receives the rays of light, we should *à priori* expect to find it so.

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* Simon's "Animal Chemistry," vol. ii. p. 419.

† Can this account for the fact of the focus of the two eyes differing, as is certainly the case in some persons, there being no perceptible difference in the appearance of the two eyes?

	Specific gravity.
Bullock, entire eye	1·0411
Lens taken from the same eye	1·1046
Pig, No. 1, entire eye	1·0803
Lens taken from the same pig's eye	1·1060
Pig, No. 2, eyeball, with portion of optic nerve attached	1·0710
Same eyeball without any optic nerve	1·0523
Portion of optic nerve alone	1·0578
Haddock, entire eye-ball	1·0324
Lens taken from the same eye	1·1684

The lens itself is also heavier than its capsule. The sp. gr. of a pig's lens, without capsule, was 1·1015; with the capsule, 1·0985. The average sp. gr. of four sheep lenses, with capsule, was 1·1152; of two lenses, without capsule, 1·1584.

HUMAN LENS.

1. Young adult man	1·1304
2. Ditto	1·1304
3. Adult woman	1·0909
4. Ditto	1·0967
	4)4·4484
Average	1·1121
5. Lens removed with anterior part of eye-ball for disease of cornea of more than two years' standing, which resulted in the first instance from granular disease of conjunctiva at the gold-diggings. The sight was quite gone, and the other eye painfully involved; the iris adhered to the opaque cornea, but the lens appeared to be perfectly natural. Its weight, however, was increased to	1·1960

Coagulation by water at 160° F. increases the density of the lens, thus—

No. 1, so treated, weighed	1·1066
2, ditto, ditto	1·1739

CAT.

Both lenses exactly alike	1·1491

BULLOCK (7 lenses).

1.	1·1071
2.	1·1078
3.	1·1114
4.	1·1046
5.	1·1111
6.	1·1097
7.	1·1079
	7)7·7596
Average	1·1085

SHEEP (6 lenses).

1.	1·1143
2.	1·1178
3.	1·1111
4.	1·1176
	4)4·4608
Average	1·1152
4. Lens without capsule	1·1562
6. Ditto	1·1607
	2)2·3169
Average	1·1584

PIG (3 lenses).

1.	1·1060
2.	1·0985
3.	1·0864
	3)3·2909
Average	1·0969

HARE AND RABBIT (5 lenses).

1. Hare	1·1248
2. Ditto	1·1065
3. Ditto	1·1234
4. Rabbit	1·1232
5. Ditto	1·1232
	5)5·6011
Average	1·1202

COMMON FOWL (5 lenses).

1. Large cock	1·1331
2. Ditto	1·1366
3. Ditto	1·0975
4. Ditto	1·0975
5. Hen	1·1250
	5)5·5697
Average	1·1139

COMMON DUCK (4 lenses).

1.	1·1600
2.	1·1600
3.	1·0952
4.	1·1052
	4)4·5204
Average	1·1301

REPTILES.

I have weighed the lens of the alligator, turtle, and chameleon, but as they had been in spirit or Goadby's solution, I abstain from giving the figures, as I am doubtful of their absolute accuracy, however, they are sufficiently so as to leave little or no doubt that the specific gravity of the lens in these creatures is intermediate between mammalia and fish.

The lens of the frog and toad is so small that it is very difficult to weigh it with absolute precision, but as the result of experiments upon eight lenses the specific gravity of them may be set down as from 1·1500 to 1·1600.

FISH (7 lenses).

1. Cod	1·2173
2. Ditto	1·2173
3. Haddock	1·1871
4. Ditto	1·1684
5. Ditto	1·1742
6. Halibut	1·1529
7. Ditto	1·1645
	7)8-2817
Average	1·1831

In estimating the sp. gr. of the lens it is essential that the eye should be perfectly fresh. If the animal has been dead any length of time the size of the lens is increased, but its sp. gr. lessened. If it has been preserved in dilute spirit its sp. gr. is diminished, while it is increased if it has been kept in Goadby's solution, which answers so well for many tissues. The action of water at and above 160° F. is very uncertain. In the hard lens of the fish it scarcely alters the sp. gr., but commonly that of the softer lenses of birds and mammalia is increased. I have therefore rejected all the calculations made from lens which were not fresh—they include the lion, several monkeys, many reptiles, many human, and other creatures.

The same remark, as to the necessity of employing only the lens of animals very recently dead, holds good in taking the measurement of its curves. It soon becomes too convex by imbibition of fluid; when preserved in spirit it also swells out; if kept in Goadby's solution it shrinks in size and becomes too flat.

Reagents act upon the lens almost as they do upon albumen, yet not entirely, for though by boiling the lens its outer portion at once becomes opaque, the inner does not, as is best seen in the solid lens of a large fish, the centre of which becomes like transparent horn, while the outer is like coagulated white of egg. So also in some of the aqueous mammalia there is a difference between the central and more external portions of the lens; thus preparations 1684, 1686, and 1687 in the College of Surgeons show a distinct dark eccentric nucleus within the pale more colourless external part of the lens; whether normal in the living eye or the result of long immersion in spirit I know not. They are from either whales or the porpoise.

The composition of the lens is given by Berzelius as—

Water	58·0
Peculiar matter (protein compounds)	35·9
Hydrochlorates, lactates, and alcoholic extracts	2·4
Phosphates and watery extracts	1·3
Insoluble membranous residue	2·4
	100·0

Simon ("Animal Chemistry," vol. ii.) says, besides albumen there is in the lens a peculiar substance resembling casein. This he calls crystalline. He gives the composition of the lens.

	In the Ox.	In the Horse.
Water	65·762	60·000
Albumen	23·290	25·531
Crystalline	10·480	14·200
Fat	0·045	0·142
Extractive matter, with chloride of sodium and lactates	0·495	0·426

That the lens consists of fibres arranged side by side, in concentric layers, superimposed upon each other, commencing at the axis and passing from one surface or pole to the other, has long been known, particularly through the labours of Leeuwenhock, Derham, and Dr. Young; and that the human lens has a tendency to split at first into three sections, and then again into smaller, ordinary decomposition or immersion in weak spirit, boiling water, and other coagulating agents, readily shows; but the exact nature and arrangement of these fibres were much debated and disputed until a recent date. We are indebted to Sir D. Brewster for the first accurate account of the microscopic anatomy of this body,* and though in all particulars his description may not be fully borne out, yet his investigations did much to reveal the wonderful complicity of the minute anatomy of the lens.

In order to examine the lens microscopically it should be rendered opaque, and hardened by alcohol, chromic acid, or hot water. If boiled for any length of time the fibres become irregular. I find immersing the lens for three or four minutes in water at 160°, and then adding to the morsel on the object-glass a drop of very dilute chromic acid, to develop the structure well. Acetic acid renders the fibres beautifully transparent and clear, but does not harden them so much as chromic, and soon acts upon them destructively. Liq. potassæ destroys them immediately, ammonia more slowly.

The lens of a large fish, the cod or haddock for instance, or of the frog or toad, should be selected for first observations, as the fibres are stronger and their markings coarser than they are in birds, mammalia, or man; and of these lenses the middle portion should be selected, as upon the outer surface or margin the fibrous character is not well developed, and near the axis the fibres are so attenuated and delicate that their serrations are not so distinct. In other respects, in all orders of animals, the fibres appear to be essentially of the same character, flattened, ribbon-like filaments, arranged side by side, so as to make a continuous layer, and connected, or interlocked together at their sides by serrations, which pass mutually into each other, just as the cranial bones do at the coronal and sagittal sutures. These serrations are by no means usually so uniform in size or number as they have been figured by Sir D. Brewster,* and they appear to me to be produced much in the same way as those in the cranial bones are, by the development and pressure of the fibres laterally against each other, and to result from the granules, of which the fibres are ultimately made up, pressing into the interstices of each neighbouring fibre; for they are most distinct in the fibres of the hardest lens, and the serrations are largest and boldest where the granules are the largest. They are better marked where the filiform character is best developed, as in the middle rather than at the axis or margin of the lens, and the serrations become particularly developed by those reagents, which have a corrugating effect upon the fibres, as chromic acid and sulphuric ether.

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* "Phil. Trans.," for 1833 and 1836.

The fibres pass from one surface of the lens to the other, but whether every individual fibre does so, as stated by Brewster, is I think, very doubtful; indeed, it is scarcely possible that all those near to the axis should do so, and, I think, many may be seen towards either pole becoming so attenuated as to be lost in, and amalgamated with, neighbouring fibres, the serrated edges and individual character being entirely lost. Each fibre is considerably broader at its middle than at its ends, towards which it gradually tapers, so that the greater width of the diameter of the lens over that of the axis is rather caused by the increase laterally in the middle of the fibres than by an additional number of fibres at this part. The depth or thickness of the fibres does not vary like the width, it appears pretty uniform in all the layers; hence, while the outer fibres are broad and ribbon-like, the inner are almost cylindrical when separated, and when seen closely packed together in a bundle they appear hexagonal. This has doubtless led some observers into the error of describing them as hollow tubes. Leeuwenhock described the number of layers as 2000 in the lens of a cod, and Sir D. Brewster calculated the number of fibres in each layer of the lens of a cod at 2500, and of the serrations in each fibre as 12,500, which is, however, by no means certain. He assumes that the breadth of all the fibres in each layer is uniform, that the breadth of the fibres throughout the whole of the layers is five times the thickness, and that the serrations uniformly equal the thickness of the fibre, all of which assumptions are incorrect, for, while the thickness is tolerably uniform throughout all the layers, the breadth of the fibres not only varies very much in the different layers, but the fibres in the same layer vary very considerably in their breadth, and the serrations are irregular in number and boldness; some being scarcely perceptible, while others pass boldly and deeply, even bifurcating, into the adjoining fibre.

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* If a lens (of the cod, for instance) be strongly coagulated and then well dried, and a layer of the fibres be seen, the serrations are more uniform and regular than if a single detached fibre be seen or they are in the recent state.

In the haddock and the cod I found a fibre, taken from near the middle layer (equidistant from the margin and axis), to measure in breadth $\frac{1}{2750}$ of an inch, of which the serrations on each side measured $\frac{1}{11000}$, or the two together $\frac{1}{5500}$, or just equal to the breadth of the solid part of the fibre. In this part of the lens I found 2700 fibres to the inch linear, while close to the axis there were 5500 to the inch; while at the extreme surface the fibres were so indistinct as hardly to be formed; where they were, they measured at least twice, or more, as much as in the middle layers. (Plate VI., fig. 3.)

In the frog, from the middle layer of the lens, I found the fibres to be about $\frac{1}{6000}$ thick and $\frac{1}{2700}$ wide, but by no means uniform in size. The ribbon-shape of these is well shown in fig. 4, where two fibres are twisted over upon themselves. In the turtle and the alligator there is a great difference in the size of the fibres, the outer being very broad and flat as compared with those near the axis. (Fig. 5.)

In the fowl the fibres of the outer layers are very wide, as much as $\frac{1}{1100}$ of an inch, as compared with those from near the axis, most of which are not more than $\frac{1}{5500}$ of an inch, but some are considerably broader. The smaller are cylindrical or slightly hexagonal, from pressure against each other, while the larger are ribbon-shaped (fig. 6). In the fowl the serrations are very slight, and the granules composing the fibres are very minute.

In rodents, as the rat, squirrel, hare, and rabbit, the fibres measure at the margin of the lens $\frac{1}{1800}$, in the middle $\frac{1}{3000}$, near the axis $\frac{1}{5000}$ of an inch; the first being deeply serrated, the latter very slightly so.

In a lens taken from a sheep just killed, I found its fibres from outer layers to be from $\frac{1}{2000}$ to $\frac{1}{1570}$ wide; in the middle layer $\frac{1}{2750}$ wide, $\frac{1}{5500}$ thick; at the axis $\frac{1}{4125}$ wide, and $\frac{1}{5500}$ thick. In the ox the fibres vary as we proceed from the circumference to the axis from $\frac{1}{2700}$ to $\frac{1}{9000}$ of an inch wide; and, as in all mammalia, the serrations are small. Fig. 8 shows a transverse section of a bundle of fibres from near the middle of the lens, in which the hexagonal form of the fibres, from pressure against each other, is seen.

In the cat the fibres do not differ materially from those of other mammalia, but are very easily rendered irregular at the edge (fig. 9).

In man the fibres differ but little from those of other mammalia. They are shown in fig. 10.

The fibres are very flexible when in a natural condition, but after coagulation very easily broken; hence they are represented by Arnold as made up of short portions; but they are certainly long filaments, most of them passing from one surface of the lens to the other. The broader surfaces of the fibres appear to merely lie in close apposition, where the layers are superimposed upon each other, and to adhere as all soft moist membranes do when in close contact, or, at most, to be weakly connected by mucus; hence the lens far more readily separates into concentric layers than do the fibres from each other laterally.

Kölliker describes the fibres to be thin-walled tubes filled with a clear viscid albuminous fluid. In this, I think, he is in error, for though I have in some instances examined lenses where the central cylindrical filaments appeared to be tubular (particularly in the rat), they have been few and some days after death: and though sometimes the edges of the larger flat fibres present a darker line, almost like a double wall, this is never seen sideways, and is probably only the effect of the edge of the fibres upon the light when not fully in focus; while in every instance, whether of mammalia, birds, reptiles, or fish, where the lens has been examined immediately after death, the appearance has been so constant that I think there can scarcely be a doubt that the filaments are really solid fibres—uniformly clear, transparent, and homogeneous at first; but by heat, reagents, or decomposition soon becoming granular, then separating into granules and disappearing. These granules are smaller in birds and mammalia than in reptiles and fish. The whole substance of the lens is harder and more dense in the latter classes than in the former, particularly in the fish as compared with the bird. In the latter the lens is soft and jelly-like throughout; the central portion, though more dense than the outer, is not so in anything like the same degree as it is in fish, where not only is the whole lens more firm, but the central part is in many genera of almost stony hardness, being difficult to cut with a knife; the difference in the density of the two elements from which the rays of light pass in entering the eyes of fish and birds being doubtless the cause of this difference in the solidity of the lens in these creatures.

The arrangement of these fibres to make up the entire lens is not less curious than the structure and connexion of the individual fibres.

In the opaque cataractous lens, the fibres seem to have undergone a sort of degeneration; they appear as though broken up; they are irregular in outline, the serrations are much less distinct and uniform, the fibres are no longer clear and homogeneous, but are granular and separated more or less from each other; the individual fibres are swelled and bulging in some parts, disconnected and broken in others, just as those of the healthy lens are after having been subjected to boiling water or coagulating reagents. These changes appear to be greater towards the circumference than near the centre of the lens; fig. 14, Pl. VI. shows fibres immediately after being taken from the eye of a woman with hard lenticular cataract.

Four principal types have been described by Sir David Brewster, to one of which, or its subdivisions, the lens of every animal may be referred.

1st. The first is the most simple, in which a single pole passes through the axis of the lens to the opposite point, to which all the fibres converge like the meridians of a globe. Upon this plan is constructed the lens of all birds, of most fish, and of some reptiles—the frog, for instance. Sir D. Brewster names the frog as probably possessing the next form of lens, that with two septa ; but I have found it distinctly with one pole. Plate V., fig. 1.

2nd. The second type is found, amongst mammalia, in the hare, rabbit, and porpoise only ; in some reptiles, and in several fish, of which the genus *Salmo* affords a good illustration. In this arrangement there is a short straight line passing through the pole from which the fibres symmetrically diverge, and passing over the margin of the lens, reach a similar line on the opposite surface, but which line is placed at right angles to the first, so that every fibre in each layer except four have their different parts lying in different planes ; thus, instead of passing directly from one surface to the other, they proceed in a curved direction round the lens. Such a lens is said to have two septa at each pole. Plate V., figs. 2, 3, and 4.

3rd. The third type is that of all mammalia except those just named. In it there are three septa, diverging at angles of 120° from each pole, the septa of the posterior surface bisecting the angles formed by the septa of the anterior surface, thus making with them angles of 60°. "There are three fibres having their origin in the anterior pole and terminating at the extremity of the posterior septa, and other three having their origin in the posterior pole and terminating in the extremities of the anterior septa, which have their parts all lying in one plane, while every other fibre of the lens forms a curve of contrary flexure in order to carry it to its proper termination in the opposite septum. Hence it follows, that with the exception of the six fibres originating in the poles, the parts of all the other fibres which constitute the margin or rim of the lens are not parallel to its axis."* This form is readily seen in the lens of almost any adult animal by the three sections into which it spontaneously separates. I think I have observed the septa to be always more regularly and distinctly marked on the posterior

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* Brewster, "Phil. Trans.," 1836.

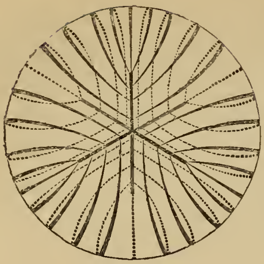

FIG. 91.

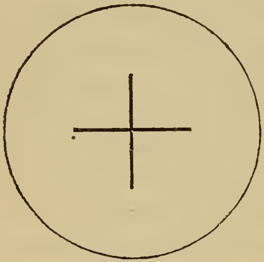

FIG. 92.

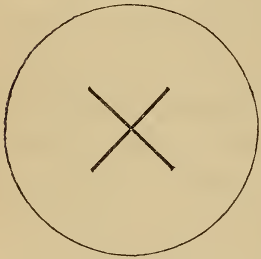

FIG. 93.

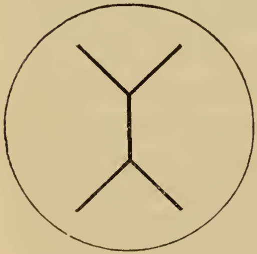

FIG. 94.

than on the anterior surface, probably on account of its greater convexity. Pl. V., figs. 5 and 6.

4th. The fourth type is when there are four septa placed at right angles to one another; and being inclined at the two surfaces at angles of 45° to each other, were the lens transparent and the septa seen at the same time, they would appear like the eight radii of an octagon, inclined 45° to one another (figs. 92 and 93). Few animals possess this arrangement; the seal, bear, and some whales being all that Brewster has found it in. Leeuwenhock described the whale as possessing five septa. In other lenses of the same animals there are two, or even three, centres of divergence, when there will be six radiations of fibres, which also are well seen in the elephant (figs. 92, 93, 94, and 95).

In the human lens the arrangement of the fibres is the most complicated of any, for while the type is the mammalian tripod, and is best seen in the fœtus, in the adult the planes are more numerous, in consequence of the primary planes immediately branching into secondary, so that a very complicated curvature of fibres exists; the septa upon the two surfaces frequently not being equal, those of the posterior being more numerous than those of the anterior. In the anterior nine septa

Fig. 91 is a plan constructed by Brewster, to show the curved direction which the fibres in a lens of the third type take in passing from one pole to the other, and which they would be seen to present if the lens were transparent.

and radiations are often found, in the posterior surface twelve, which Arnold regards as the more common arrangement in man. This complicity, however, is only in the more superficial layers, for towards the axis the normal mammalian triseptal division is preserved. Pl. 5, Figs. 7 & 8.

The general arrangement of the fibres of the lens in different creatures is most easily seen by immersing it for a few minutes in water at 180° F., then allowing it to dry in a warm room. In two or three days it will be found to have split into different sections, according to the direction of its septa, while the fibres then form good microscopic objects, and are easily preserved by simple mounting in glycerine, but if kept in water they soon swell, the edges become very irregular, the substance granular, and then breaks up.

Of the reason for these varying planes, or why they should differ so much in different animals, we are in complete ignorance; no plausible conjecture has been offered. It has been suggested they are for the purpose of enabling the curves of the two surfaces of the lens to be modified so as to adjust the eye to vision at different distances. It for long has been a favourite idea with some anatomists and opticians, particularly with the latter, that this power of the eye to overcome the aberration of parallax resides in the lens itself. It was this preconceived notion that led Sir E. Home, to describe the structureless suspensory ligament of the lens as muscular, and determined the celebrated Dr. Young to see true muscle in the serrated albuminous fibres of the lens itself, and Porterfield to assert the contractile property of the ciliary processes; but that the complicated interlockings of millions of

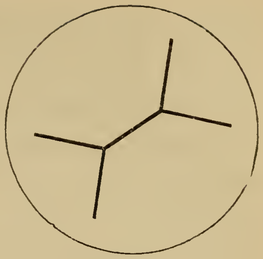
Fig. 95.

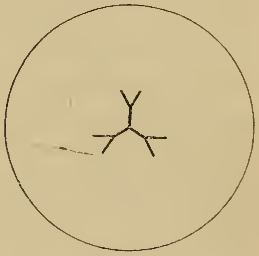
Fig. 96.

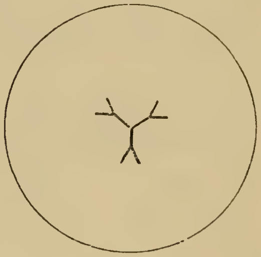
Fig. 97.

serrated fibres, arranged in planes of varying curvature and number, should conduce to easy and constant modifications in the form of the lens is not a very probable supposition. The idea, that they are for the purpose of preserving under every circumstance an unchanging density would seem the more plausible notion.

The capsule of lens is a perfectly transparent structure, which, though apparently so dense, is very permeable, and, like most animal membranes, allows exosmose and endosmose very readily to go on. If placed in air the lens soon desiccates; if put in water the capsule in a short time becomes swollen and ultimately bursts from the fluid which has passed through it; if punctured when so distended, its elasticity forces the water in a jet through the aperture. Doubtless it is through its pores the lens receives nutriment, as it is non-vascular. In structure the capsule differs *in toto* from the lens; none of the agents which render the lens opaque affect in the least the transparency of the capsule, which it retains for long after death. It is highly elastic, and closely embraces the lens, whose form, I imagine, it tends most importantly to preserve by an equable pressure. It is hard, dense, and strong; yet it is readily torn, and is cut with a grating noise. It is so elastic that when divided it at once curls up, and that always in a plane opposite to what it is laid down in. If injured in the living eye, by even a very small wound, it often forces the lens to escape into the aqueous chamber. In its physical and chemical characters it appears to be identical with the inner elastic layer of the cornea. It is quite structureless, and like it has a single layer of epithelial cells upon its inner surface. (Fig. 84.) Though when in a normal condition it long remains unchanged by either reagents or decomposition, very slight injury during life, as the least puncture, at once renders it opaque, its elasticity is then lost, and it frequently becomes a source of great annoyance to the surgeon by the persistency with which it will remain expanded across the pupil.

The inner surface is lined throughout by a single layer of cells, similar to those found on the inner aspect of the cornea. The cells are very transparent, are nucleated, and polygonal (pl. vi. Figs. 11 and 12), but this I think results from mutual pressure, for when detached and allowed to expand by immersion in water they become circular, or nearly so. These cells appear to form the connecting medium between the capsule and the lens itself. Were it not that similar cells are found in Petit's canal, I should feel inclined to think they are not merely the means of nutrition to the lens, but that they are lens-fibres in process of development. Any wound, however small, in the capsule during life, almost invariably leads to opacity and absorption of the lens. The anterior portion of the capsule is considerably—three or four times—thicker than the posterior half of it. This probably arises from the expansion of the suspensory ligament over it; or, if we suppose the latter to be an extension from the capsule, from its passing off from the capsule, just anterior to the margin of the lens, to form the anterior wall of Petit's canal, where it is striated, from the continuation of the folds, which are received between the ciliary processes (zone of Zinn). At this point of the capsule, just anterior to the margin of the lens, there is a sudden thinning of it, and after turning over the edge of the lens, the posterior capsule, though in other respects identical with the anterior, is much thinner and weaker.

In a few hours or days after death the capsule is found separated from the lens by one or two drops of interposed fluid. This is the *liquor Morgagni*, and until very lately has been considered as a normal condition of the living eye. This, however, it certainly is not, for if the lens of any creature be examined immediately after death no fluid whatever is found; indeed, we can hardly understand how the vitality of the lens could be maintained, or the lens be kept steadily *in situ*, which for the purpose of vision would appear to be absolutely necessary, were it surrounded by a bath of aqueous fluid, however small. The least pressure of the muscles of the eye-ball would induce an oscillatory motion of the lens. The fluid is a *post-mortem* effect; it is derived from the breaking down of the epithelial cells, and by endosmose from the aqueous and vitreous humors.

In the adult neither vessels nor nerves can be traced in the lens or its capsule; they are therefore regarded as extra-vascular; but during fœtal life, up to the period of birth, and even some little time afterwards, both contain vessels; indeed, the capsule is then covered with a beautiful network of blood-vessels, derived, principally, from the central artery of the retina, by means of a considerable branch, which passes directly through the vitreous humor to the centre of the posterior capsule, where it minutely subdivides, the vessels forming a very free inosculation with each other. Plate III. fig. 7. As they approach the edge of the lens, which at this period does not fully reach the margin of the capsule, and is somewhat irregular at its circumference, they have a tendency to run in pairs, and pass directly straight over the edge on to the anterior surface of the capsule, where they again spread out and form a stellate network; plate III. fig. 6, but at the period of birth not so free as upon the posterior capsule; here they inosculate with other branches derived from the ciliary processes and iris, which at this period of life is in contact with the lens.

AQUEOUS HUMOR.

The aqueous humor is that small quantity of fluid, amounting to from four to six grains, according to the convexity of the cornea, which is contained in the space bounded by the posterior surface of the cornea and the anterior of the crystalline lens. Chenevix gives its specific gravity as 1·0003—Henry as 1·009, which though perhaps too high is probably nearer the truth than Chenevix's estimate: according to Berzelius it is composed of

Water	98·10
Albumen, a trace.	
Muriates and lactates	1·15
Soda with animal matter soluble in water .	0·75
	100·00

Dr. Henry makes the solid residuum as much as eight in the hundred parts, instead of, as Berzelius does, less than two.

Though the quantity of the aqueous humor is small its uses are very important, they are, first to maintain the due curvature of the cornea, and thus enable it accurately to refract the rays of light, for when the fluid escapes the cornea falls flat and vision is instantly seriously impaired or altogether lost; secondly to afford a medium of nearly the same density as the iris, for it to be suspended in, by which it moves with little force and is equibably supported as a plane surface at a due distance from both the cornea and the lens. If the humor escapes the iris either falls forwards upon the cornea, or backwards upon the capsule of the lens, generally the former, to which it contracts permanent adhesion, and vision is impaired. Thirdly, the aqueous fluid forms a concavo-convex lens, of somewhat less density than the concavo-convex cornea, and unequal double convex lens; and thus assists in forming that compound lens of the whole eye, by which the instrument is rendered practically achromatic.

By the iris the space is divided into two chambers, the anterior and the posterior, which communicate through the pupil. The anterior is in every direction considerably the larger of the two, its capacity being from eight to ten times that of the posterior chamber. The *anterior chamber* is bounded, anteriorly by the epithelial covering of the elastic corneal lamina, laterally by the fibres (pillars of the iris,—ligamentum pectinatum) which pass from the cornea on to the iris,—and posteriorly by the anterior surface of the iris, or its epithelial covering, supposing it to possess one, as according to Kölliker it does. The *posterior chamber* is bounded posteriorly by the anterior crystalline capsule, by a small ring of the suspensory ligament of the lens, where it forms the anterior half of Petit's canal, and by the points of the ciliary processes; laterally by the union of the ciliary processes with the iris, and anteriorly by the uveal surface of the iris (figs. 83 and 84).

By many anatomists, and by none more strenuously than Dalrymple, it has been contended that a peculiar delicate membrane called the *aqueous membrane* lines the entire surface of these two chambers, passing through the pupil, and thus forming a shut sac which secretes the fluid, and thus is analogous in form, structure, and function with the serous sacs. The arguments, however, by which they support the idea are rather drawn from pathological than anatomical considerations, and also deductions from the mode of formation and disappearance of the papillary membrane. By most anatomists who have recently carefully investigated these structures this opinion is regarded as unfounded. All agree that the inner surface of the cornea is lined by an epithelial membrane, most that the posterior chamber is not so lined, while as regards the anterior surface of the iris, as has already been mentioned, Bowman declares no epithelial cells are to be found upon it, Kölliker as distinctly says there is a layer: while in some few cases I have certainly thought I have found them, in the great majority of examinations I have searched for them in vain.

The smallness of the central part of the posterior chamber and the close proximity of the iris to the lens when the pupil is contracted is a subject of the deepest importance to the ophthalmic surgeon both in operations and diseased conditions of these parts; and points out the absolute necessity of in many cases dilating the pupil freely, if for no other reason, than of keeping it free from the convex centre of the lens. This however is rather a pathological than a simple anatomical consideration.

In the fœtus, as has already been pointed out, the presence of the membrana papillaris completely separates the anterior and posterior chambers into two distinct cavities. At this period both chambers are very small.

CHAPTER V.

ON THE EYES OF ANIMALS.

The minute structure of the various tissues composing the eye-ball has already been described. I do not now propose to enter upon an elaborate and detailed investigation of all the variations found in animals, but only to give such an account of the organ as will enable the student to understand the modifications met with in the different classes of animals, and how these are adapted to the various conditions of animal life, and to briefly trace up the eye from its simplest form, where mere perception of light is its only function, to the fully-developed complex organ of man, whose power is so to speak as much mental and intellectual as physical; for mere perception of light is almost valueless to him.

In addition to the varied forms of the dioptrical instrument of man, which is distributed very widely, indeed, almost as widely as vision itself, we find in a very large class of creatures—the *articulata*—a new form of apparatus, of most astonishing, almost miraculous, construction introduced, in which advantage is taken of that other law in optics—radiation of light, whereby the image of an object may be obtained. (See page 66.)

It will be the most convenient plan to commence at the lowest point of investigation and proceed upwards.

It is a question of great difficulty to decide with certainty where eyes are first to be found; hence there still exists much difference of opinion amongst comparative anatomists as to the form of animal in which a distinct organ of sight is first seen.

There are a great number of creatures of very simple organization which evidently conduct themselves differently under variations of light or heat, some seeking and enjoying it, others carefully avoiding its presence; these creatures are supposed by some persons only to be enabled to do this by the possession of some special organ of vision, but in many of them by the most careful examination no such apparatus can be detected, whilst the presence of it is rather inferred from the supposed necessity for its existence than from any proof of it. I much incline to the opinion that this faculty is rather owing to the general surface perceiving variations in the degree of heat which almost invariably accompany changes in the intensity of light, than to the presence of an eye;—in fact, that it is to be referred to the sense of touch rather than to that of sight. That this is so with some of these creatures is certain. Thus the hydra moves towards the light while the actinia shuns it when strong, both are without heads, and there is no instance of the existence of either eye or ear where there is not a head.

The small red spots seen in many of the POLYGASTRICA are thought by Erenberg, Grant, and others to be eyes, while Rymer Jones, with far more probability, denies that these coloured spots are eyes; for not to mention their varying size and colour according to that of the medium in which the creature may be placed, if they really do constitute organs of vision, they form an exception to all we know of the proceedings of nature, for these spots are most developed while the young are still contained within the body of the parent, and disappear when they are set at liberty,—a time at which it would be thought eyes are most required if possessed by a creature.

There is the same difference of opinion as to the presence of eyes in that numerous and widely distributed class of animals, the ACEPHALA, in some of which, the *Medusa aurita*, for instance, in the margin of the disk a number of red or purple spots are found, which have been supposed to be eyes, apparently without ether reason than their colour, which in the absence of structure is certainly not sufficient to justify the assertion of the existence of an organ of special sensation; though I am not disinclined to allow that the mere aggregation of pigment particles into globular masses may be the first step in the arrangement of a structure for the perception of light. We find colouring matter almost invariably in the eyes of higher animals, and if we admit, which is highly probable, that caloric and light are but variations in the intensity of the vibrations of one ether, as the violet rays of the spectrum are produced by more intense vibration than the red, so it may be that the actinic rays may be merely more intense vibrations than the violet, and the calorific less intense than the red rays: and as the auditory apparatus of some creatures appears to be enabled to appreciate vibrations too intense, and of other creatures too slow to be heard by our ears, so it may be with the eye, and it is possible that these coloured spots may be sensitive to rays of which our organs take no note; and thus though sight can hardly be said to exist, some sort of appreciation of light may be possessed by these spots, for the sense of vision is not suddenly developed. Nearly the same remarks will apply to the ENTOZOA, the EPIZOA, the ROTIFERA, and the ECHINODERMATA. In the two latter from their active locomotive powers and their certainly possessing a simple nervous system we might be prepared to expect the presence of an eye; and it is far from improbable that the red spots described by Erenberg as eyes may really be such, though no distinct structure has been demonstrated and the existence of which Jones denies.

The earliest indication which we with certainty have of the presence of a special organ of sight is in the ANNELIDES, or worms. The organ consists of a small simple globule. These vary much in number and arrangement in different species. In the *Nereis* there are four of these dots arranged in a quadrangle upon the surface of the head as shown at *a a*, Fig. 98, which represents the anterior part of one of these creatures. In the common leech there are ten of these eyes, arranged in a semicircle round the fore part of the head, just above the mouth. Each presents a slight prominence covered by a transparent portion of skin,* Fig. 99.

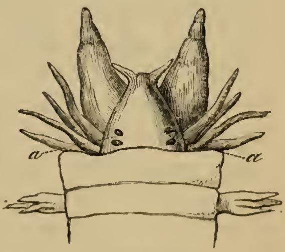

FIG. 98.

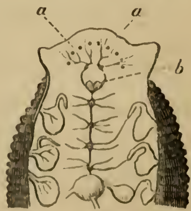

FIG. 99.

The dot appears to consist of a cup-shaped black membrane containing a round white opaque body, which seems to be a prolongation of the optic nerve. In some species of annelides the black membrane is entire, in others there is an aperture. It is probable these creatures are destitute of any dioptrical apparatus: there is merely a bulbous expansion of the optic nerve surrounded by a black choroid coat. It is most probable that this apparatus would only enable the animal to distinguish light from darkness, fig. 100.*

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* Fig. 99—*a a* the eye dots; *b* the mouth of the leech.

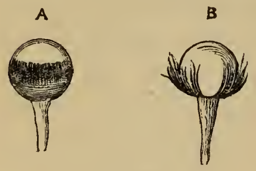

Fig. 100.

Mollusca.—In the *Acephalous* or bivalve mollusks, such as the cockle, muscle, and oyster, as there is no trace of a head properly so called, so nothing like an eye has been discovered. Indeed from most of these creatures generally being fixed immovably in one position, depending upon the currents of water for bringing their food, and to the sudden closing of the shell for their defence, it is difficult to conjecture of what use an eye would be to them. A delicate sense of touch is valuable, but an eye would be useless. Those mollusks, however,—the *gastropoda*, which inhabit a single shell, and enjoy free locomotion, crawling about upon the large fleshy foot, have the senses much more developed. They have two or four tentacula and very commonly upon these, upon the upper pair where there are four, are to be seen small black elevations, which in some, as the *Cypræa tigris*, from the South Seas, and the common snail of ponds, *Lym. stagnalis*, are placed about the middle of the single pair of feelers; in some creatures they are at the base, and in many others as the common garden snail and slug they are placed at the very apex, forming the club-shaped termination of tentacula. These are the eyes, and consequently are capable of being considerably projected, and of being withdrawn within the body and also of being turned in every direction as the tentaculum is moved. If an inch lens be used the soft skin of the tentaculum as it passes over the tubercle is seen to become hard and transparent, that in fact it forms a cornea. If the tentaculum be now slit up a small black globule is found lying imbedded in a large tuberculous expansion of the optic nerve. Within the choroid cord is a vitreous humor, having imbedded in the anterior part of it a perfectly globular crystalline lens, which if I am not deceived is composed of fibres passing from one pole to another as in fish and birds. Thus are found all the essential parts of an eye—a transparent cornea; a black choroid coat, with an aperture in it, corresponding to the cornea, and forming an iris; a crystalline lens; a vitreous humor; and an optic nerve, developed into a pulpy expansion or retina. Fig. 101.* Swammerdam describes and figures an aqueous humor, in the snail, Muller says the optic nerve is altogether a distinct branch of the supra-œsophageal ganglion, Grant thinks that it is a branch from the common nerve of the tentaculum. I have figured it as I have found it in the slug. The nerve is much convoluted to allow of the projection of the tentaculum without strain upon it.

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* Fig. 100, A the eye entire; B the choroid coat, partially removed to show the bulb within, and its continuation with the optic nerve.

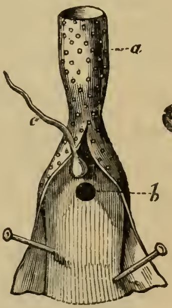

FIG. 101.

The ARTICULATA form a very large class, the majority of which are amongst the most active moving creatures in existence: they are insects, arachnideans, and crustaceans. The eyes of these creatures have been aptly described as "a world of wonders" by two of our most celebrated naturalists. In vertebrate animals two eyes are found: but in insects they are numbered by thousands. There are at least four different kinds of eyes in these creatures:

1st. Simple eyes—stemmata, ocelli, or eye-dots.

2nd. The conglomerate or aggregate eye, which consists of a number of simple eyes, grouped together, each, however, being distinct and perfect in itself.

3rd. Compound eyes, which are made up of an immense number of tubes, each tube being a separate optical apparatus.

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* Fig. 101, *a* represents the tentaculum of the common black slug, *Limax ater* turned inside out, cut open and magnified: *b* the choroid *in situ*: *c* the optic nerve with its bulbous expansion: *d* the eye-ball removed to show the aperture in the anterior part of choroid corresponding with the cornea. See description by myself of the anatomy of the Limaces found in the neighbourhood of Leeds. Trans. of the Philosophical and Literary Society of Leeds, 1834.

4th. Eyes analogous to the compound, but differing in having a cornea common to the whole series of tubes, instead of being divided into as many facets as there are tubes.

1. The simple eyes, or stemmata, are very widely distributed amongst the articulata. They are the eyes of most of the larvæ of perfect insects, (some few larvæ do not possess eyes, and some few have compound eyes,) of all the arachnoida, as spiders and scorpions: and many of the perfect insects possess them in addition to the compound eyes. They vary greatly in number, size, and position, but in all, so far as is known, their structure is similar. That of the scorpion may be taken as the type, Fig. 102* in which there is a clear transparent cornea, immediately behind which is a globular lens, which rests upon a cup-shaped vitreous humor, expanded on the convex posterior surface of which is a retina derived from an optic nerve, and exterior to the retina is a black choroid coat, which being continued partially behind the posterior surface of the cornea, on the anterior part of the vitreous humor, there forms a rudimentary pupil.

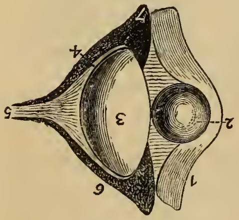

Fig. 102.

The colour of these stemmata varies much, in many insects it is black, but in some, as the goose louse, these eyes are white and shining. In spiders they are often of sapphirine colour, and clear as crystal. In some spiders and scorpions the centre is dark and the circumference paler, which gives to these creatures a fierce and repulsive glare. In some, as the tarantula, the pupil is clear and red as ruby, while the iris is of the colour of amber.

The number and position of these eyes vary greatly. They are always immoveable, hence probably their great number. They are often arranged so as to command a large field, sometimes a complete circle of vision. Fig. 103* represents the position of the eye in the scorpion; there are three small eyes on each side of the margin of the fore part of the head, and further back near to the middle line is an eye of much larger size. The difficulty of catching a spider is well known. This is accounted for by the position of the eight eyes, which are so arranged that no object can approach from any direction without the creature seeing it. Fig. 104 is an outline of part of the spider to show the position of its eyes, *a a*, and Fig. 105 is Leeuwenhock's view of a spider's head, in which the character and form of the eyes are well shown. Fig. 106, also from him, is the half of the head of a silkworm, which possesses twelve such eyes. Fig. 107 shows the stemmata of a caterpillar, where there are eight arranged in a circle connected together by a common black choroid membrane: each eye however is distinct from the others, and receives a separate branch from the common optic nerve.†

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* Fig. 102, eye of scorpion; 1 cornea; 2 lens; 3 vitreous humor; 4 retina; 5 optic nerve; 6 choroid coat.

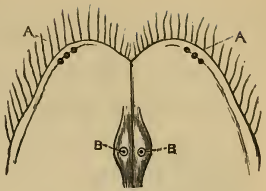

FIG. 103.

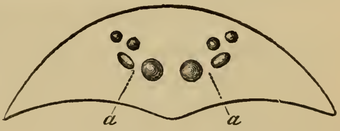

FIG. 104.

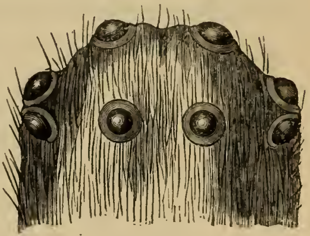

FIG. 105.

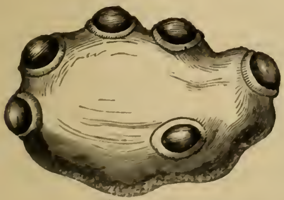

FIG. 106.

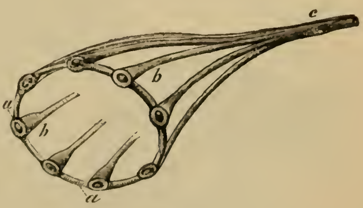

FIG. 107.

2. *The conglomerate or aggregate* eyes differ in no respect

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* Fig. 103, outline of head of scorpion; A A three anterior eyes; B B larger posterior eyes.

† Fig. 107, eye of caterpillar; *a a* the eye-dots; *b b* filament of optic nerve going to each dot; *c* the common trunk of nerve.

from the simple stemmata except that they are very closely grouped together. The structure of eye is however distinct from that of the others as in the ocelli. The arrangement is varied in form as well as in numbers. In the *Scolopendra forficata,* the eye consists of about twenty continuous pellucid lenses, arranged in five lines, with a single larger one behind them, as though it were a sentinel or scout placed at some little distance from the main body. In the common millepede, *julus terrestris,* there are twenty-eight of these eyes, arranged in seven rows so as to form nearly an equilateral triangle. Fig. 108. In other insects, there is a similar arrangement.

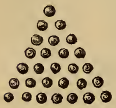

FIG. 108.

3. *Compound Eyes.*—There are usually two of these eyes—one being placed on each side of the head—but occasionally they are situated so near to the median line as to appear to form only a single central eye. Most commonly in insects the eyes are sessile, but in some few instances they are placed upon an elongated tube, something like the pedunculated eye of crustaceans, but unlike them they are immoveable as in Fig. 109, which shows the columnar eye of a small Ephemera. In other insects the eyes are flat and do not rise much above the general surface of the head; in others, however, they are nearly hemispherical, as in the Fulgora laternaria, Fig. 110, and the shrimp, Fig. 111. In others again they form elongated curves—as in some beetles. Fig. 112. In some insects the eyes are very small, while in others they considerably exceed the head in size, and their facets may be seen by the naked eye.

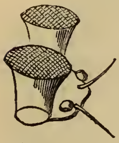

FIG. 109.

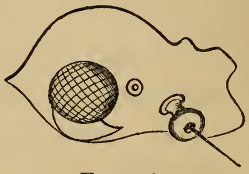

FIG. 110.

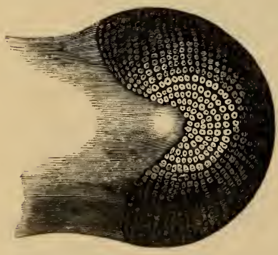

FIG. 111.

The colour in many insects of these compound eyes is most brilliant. The beautiful iridescent eye of the common dragon fly is well known to everybody. In certain insects the colour is a bright green, in others of the finest gold, in some the eye is purple and green, in others spotted, and when examined under a microscope the facets of the clear transparent cornea look like a host of diamonds set in the purest gold, mingled with other gems innumerable, forming a glorious jewel of the most marvellous splendour.

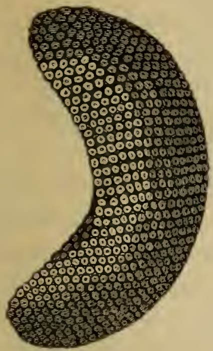
Fig. 112.

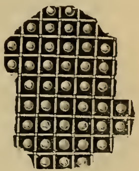
Fig. 113.

A good pocket lens will exhibit the hexagonal form of the compound corneæ of the larger insects, but those of the smaller require to be placed under the inch or half-inch object-glass of a microscope. In the crustaceans, as the shrimp, Fig. 111, and some few insects, as the Phalena, Fig. 113, the facets are square, but in by far the greater number of insects the facets are hexagonal, as in the cockchafer, *Melalontha vulgaris*, 114.

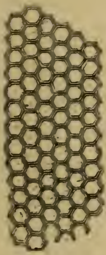
Fig. 114.

The internal arrangement of the compound eye will be learnt by an examination of Figs. 115, 116, 117, 118, and 119, which are taken from Leeuwenhock, Straus Duckheim, and Dugès, to whom, with Müller, we are indebted for most of what is known of these wonderful structures.

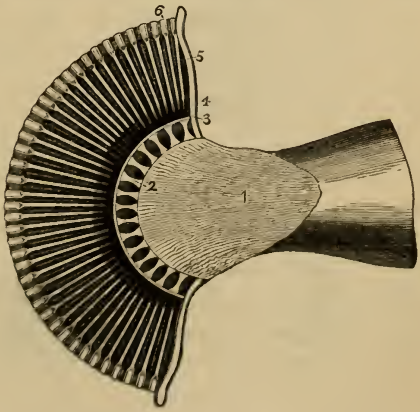

Fig. 115.

Fig. 115 represents a section of the eye of the common cockchafer, from Straus Duckheim, and Figs. 116 and 117 are still more magnified views of the same parts. 1 is the optic nerve coming from the brain, or supra-œsophagal ganglion. The nerve swells out into a large gangliform enlargement, and then sends off a large number of branches, 2, which pass as far as a layer of pigment 4, called the common choroid coat, behind which they unite into a delicate expansion to form a common retina 3, from which pass off an immense number of filaments 5, corresponding in number with the corneal facets; they pass through a dense black choroid to spread out in a pyriform form, Fig. 116, 6, upon the ends of the transparent hexahedral prism 7, Fig. 116. The anterior ends of these being applied to the corneal facet act as so many vitreous humors or lenses. The corneal facets 6, Fig. 115, 8, Fig. 116, are double convex lenses.

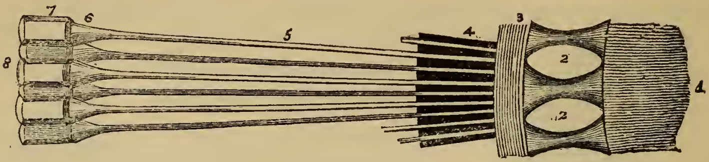

Fig. 116.

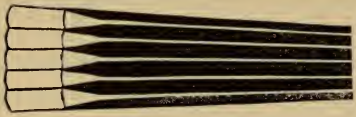

Fig. 117.

Dugès and Muller give a somewhat different description of the eye of the *Libellula vulgata* or dragon fly, a difference which may actually exist, and if it does not such slight discrepancies in accounts by different observers of structures so minute and complicated only prove their general accuracy. Figs. 118 and 119 illustrate Dugès' account, according to which the facet of the cornea, 1, is a miniscus lens, having a long focus, within the cornea is a dark membrane or choroid coat 2, which encloses a cylindrical vitreous humor 3, between the vitreous humor and the cornea there is a small hole in the choroid coat 4, constituting a pupil: as the cornea and vitreous humor do not quite touch each other, a small space is filled with aqueous humor 5; each vitreous humor, 3, is imbedded in the black choroid coat 2, by which it is completely separated from all the others, and

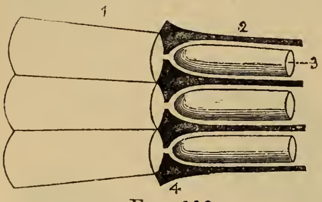

Fig. 118.

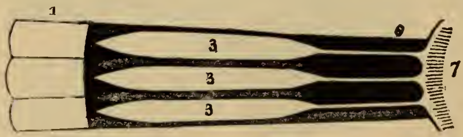

Fig. 119.

posteriorly tapering to a point it receives a filament of nerve, 6, fig. 119; these nerve branches pass separately through a dense colouring matter, and unite in a common optic ganglion, 7.

Fig. 120, taken from Lieuwenhock, shows the mass of filaments of the optic nerve, from the compound eye of the common domestic fly; as the eye is convex, the filaments will be of varying lengths to reach the different facets of the corneas.

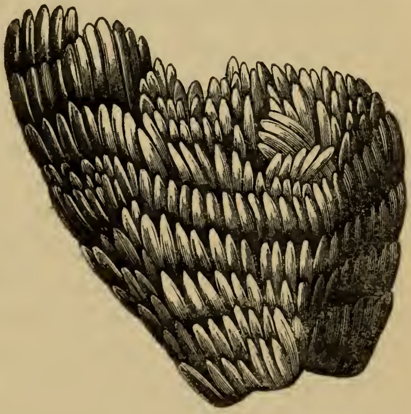

Fig. 120.

The number of the eyes is at least as astonishing as the complex arrangement of them. The following table will show the number of eyes computed by different observers to exist in some insects:—

Ant	50
Scarabeus	3,180
Lobster	5,000
Silk moth	6,236
Common house-fly	8,000
Horse-fly	7,000
Cockchaffer	8,820
Ligniperda Cossus—goat moth	11,300
Butterfly	17,325
Dragon-fly	12,544
Mordella	25,088

In those articulata which do not undergo the peculiar insect transformation, the two kinds of eyes are not usually found. In spiders and scorpions there are only the simple eye,—numerous, because fixed, otherwise they would only be able to see in one direction. While the crustaceans, at least the higher of them, as the lobster and crab, have the compound eye placed upon the extremity of a moveable foot-stalk, which, by a special muscular apparatus, they are enabled to direct at will. This contrivance is probably in consequence of their hard shell preventing that motion of the head which insects possess. In some there is a fissure or depression in the dense case within which the eye and its pedicle may be withdrawn or laid flat, so as to be protected from injury.

The general effect of the arrangement of the compound eye will be as though a series of tubes were placed round a curved surface; and the extent of vision will be in proportion to the size of the sphere of which the eye is a segment, and its projection above the general surface. If the eye be flat or mounted upon an immoveable tube, as Fig. 109, of course it will only see in the direction of the facet; on the contrary, if the eye be on a moveable pedicle, the range of vision will correspond to the length and extent of motion in the stalk; and, if the eye be hemispherical, the field will be in proportion; if two such eyes be laterally placed, vision will be almost panoramic. In the perfect insect, besides the compound eye, there are generally three, sometimes only two, and occasionally four or more, simple eyes, placed near the fore part of the head.

It is curious to observe that even here where nature appears to be so lavish of her powers she is really careful, for where the eyes are projecting and thus form so much of spheres as to have the inner sides of the two opposed to each other, and where consequently the inner side of one eye would command the same view as the outer side of the other eye, no facets are found on the inner surface as in Fig. 111, where in the shrimp no trace of cornea is found in the opposed surface of the two eyes.

It has been said that little is known of the respective uses of the two kinds of eyes. In this I can hardly agree. That the subject is altogether free from difficulty will not be asserted, nor that it is easy by experiment to determine the precise functions which each kind of eye performs. Yet, nevertheless, there are, it appears to me, two methods of investigation, each of which is satisfactory, and, when compared together, decisive. 1st, The structure of the two kinds of eyes, what on known optical principles will be the effect upon rays of light in the formation of an image? and, 2ndly, what are the habits of the creatures, in which the two kinds of eyes are separately or in combination found to exist, and the position which the eyes occupy?

The ocelli are, so far as is known, all constructed upon one uniform plan, similar to, if not identical with, that of the snail and slug, or the scorpion. In the first, the light, being admitted through a transparent part of the skin, falls upon a perfectly globular lens, to pass through a small thin vitreous humor before it reaches the retina; this is an apparatus which will converge diverging rays to a near focus. In the eye of the scorpion the retina is expanded upon a larger vitreous humor, and the cornea is flat, hence, though the lens is globular, and the eye is fitted to converge diverging rays to a near focus, it will have a somewhat wider range of distance than the eye of the slug.

The compound eyes are of a totally different character. They form a series of very minute tubes with blackened sides arranged round the optic nerve, as radii diverging from a centre, more or less convex, and a greater or less segment of a circle, whose diameter varies much in different insects. The outer extremity of these tubes is the corneal facets, which can possess very little, if any, converging power, for though the whole cornea is sufficiently convex, if it were one surface, to produce considerable converging effect, yet as each facet is separated from all the others by a row of hairs, which grows between them, it will rest at right angles upon the tube which it covers, and receive perpendicularly the ray of light which falls upon it, so that little effect will be produced by it upon the course of the ray; or, if the facets are curved, as represented by Dugès, the meniscus is so slightly converging that the focus will be a very long one, besides which the tube is so very small that it will admit to pass along it but little more than that ray which enters it perpendicularly. Now it is obvious such an apparatus cannot concentrate diverging rays, and that but very few diverging rays, or those from a near object, can enter it, or, if they do enter, can reach the bottom of the tube where the nerve is situated, for they will strike the darkened sides and be destroyed; but that parallel rays,—those which come from a distant object, can not only enter the tube, but reach its bottom. The extent of vision will be in proportion to the curvature of the whole eye; if the eye be very flat, the field of vision will be very limited; lateral objects cannot be seen at all; only those objects which are in front of the eye, and at some distances from it, will be distinctly seen, all others will be very indistinct from the few rays from them which can reach the retina; bnt if the eye be very convex, so as to form a considerable portion of a sphere, then as the tubes will radiate in straight lines towards a greater number of degrees in the circle, so rays of light may enter more laterally, and probably objects placed nearer to the eye may be more distinctly seen. The effect of a larger segment of a larger or more elevated sphere being formed by the tubes which constitute a compound eye, in enlarging the field of vision, is illustrated by Fig. 35, p. 68; and also by Fig. 121, which may be supposed to be a portion of the compound eye of an insect. It is obvious that if a number of similar tubes were added on each side of those shown, the field of vision would be increased in a corresponding degree, and rays would enter one or other of the tubes, from as many more points as would be perpendicular to the spots the rays came from.

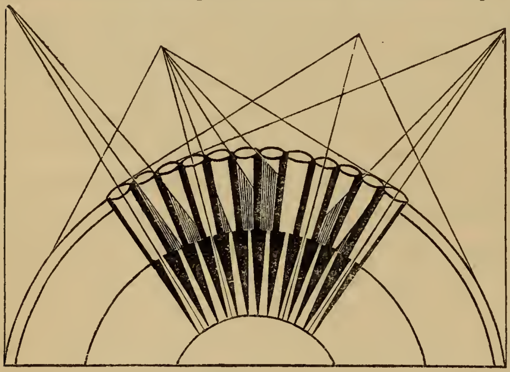

Fig. 121.

If we now attend to the habits of the creatures in which these two kinds of eyes are found, they will be seen to be in perfect accordance with the construction of the optical apparatus possessed. The larvæ of those insects whose metamorphosis is complete have only the simple eye-dot, and the condition of life in them is nearly identical with that of the annelides and gastropod mollusks. Their power of perception is dull, and their locomotion very limited, being almost confined to the mere search for food, which in most instances is rendered still easier by the egg, from which they are hatched, having been deposited upon, or in the immediate vicinity of, the food upon which the creature feeds. The sight which they enjoy or require is limited to objects placed very near to the head, in the fore-part of which these ocelli are always found.*

On the other hand, the imago, a perfect insect, is endowed with very active locomotive powers. During its brief life it is perpetually upon the wing, many of them not in search of food, but of a mate and a suitable nidus for depositing their eggs. While those insects whose life is more prolonged, as in the bee for example, which for a lengthened period is seeking food, the flight is far and prolonged, and the necessity for seeing at considerable distances certain, while their work and habits also require near vision. Now in these both the compound and simple eye are found, as Figs. 109 and 110 show. The more perfect the metamorphosis is, and the more distinct are the two stages of the creature existence, so are the forms of the eyes in the larva and imago more distinct. When, on the other hand, the metamorphosis is not so complete, and the conditions of life are not in such contrast, the distinction in the two kinds of eyes is not so complete, some insects possessing both kinds of eyes in each condition of life.

Many experiments have been undertaken by different persons for the purpose of determining, by obstructing vision through one or other of the eyes, the exact purpose to which each is subservient; the results on the whole tend to support the view above taken, but they are sufficiently contradictory not to be of much value; and the difficulties in the way of making experiments of an unexceptionable character are so great that I should much rather rely upon such general consideration as the optical construction of the apparatus, and the habits of the creature, than upon them.

In *cephalopods*, the eye is found more developed, and more nearly approaching in its general character those of vertebrata than any of the other invertebrata do. In those cephalopods whose shell is heavy, and whose power of locomotion is small, the *Nautilus*, for instance, the eye is most simple. It is supported upon a pedicle, and does not very materially differ from those of the highest gastropods. But in the more active dibranchiate cephalopods, as the poup or cuttle-fish, the eye is of very large size, and very conspicuous; and inasmuch as great stress has been laid upon the structure of the eye in these creatures, as affording an argument against the retina being the seat of vision, it is of some importance and interest to examine more in detail the construction. Fig. 122 represents the section of the eye of a cuttle-fish. The eye is partially lodged in the imperfect cranium, and is covered with the strong integuments of the head, A A A, which gradually becomes attenuated, and passes over the anterior part of the eye-ball, where it is transparent, and represents the cornea B, although not in connexion with the ball itself; beneath this transparent part, the skin forms a fold or rudimentary lid, C. There is no other cornea than the transparent skin, and in contact with it is the large crystalline lens, D D. There is no proper aqueous humor. The sclerotic E E is hard, shining, and dense; it fills up the large cavity of the orbit, and has anteriorly a large opening, posteriorly a great number of small ones, through which enter the filaments of the optic nerve F, which then expand into a large ganglion G, and form a membrane, which has been called a retina I. This lines the sclerotic coat, and is continued as far forward as the lens into a deep groove H in which it enters, and helps to retain it *in situ*.

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* Let any one take a common black slug or garden snail, place it upon a table or a cabbage leaf, or other vegetable substance, and wait awhile until it crawls naturally about: by then watching its movements, and the manner in which the upper tentacula, where the ocelli are placed, are directed according as different substances are suddenly or gently interposed in its path, or it approaches a dark object, and he will, I think, be convinced that these are not mere feelers, but that there is also some sense of vision for near objects.

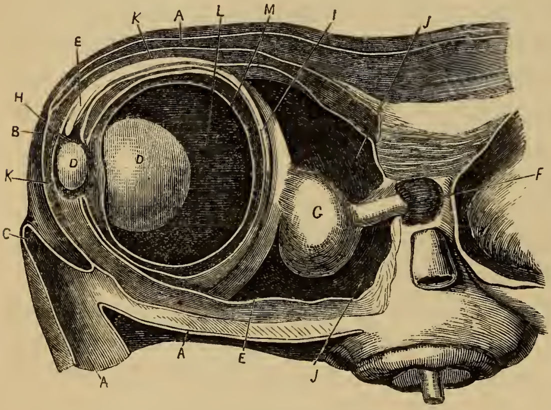

Fig. 122.

Between this expansion, or retina, as it has been called, I, and the vitreous humor L, is interposed the dark choroid coat M, which being placed anterior to the nervous expansion, thus cuts off the rays of light, and has consequently excited much speculation.

Professor Owen has however declared that there is a nervous layer anterior to the choroid, in the same situation the retina occupies in quadrupeds, and that although it may be difficult to discover the connexion between the anterior and posterior layers, yet he has no doubt the anterior is composed of the fibres of the optic nerve, and that it constitutes a true prepigmental retina.

The crystalline lens is deeply imbedded in the vitreous humor, the space between it and the retina being small. It is dense and spherical, and it is curiously divided by a dark membrane which enters deeply into its structure into two unequal parts, thus making it, as Jones aptly remarks, very similar to a Coddington lens, and which secures for its convexity a larger field of vision than any other form could do.

Though in many particulars the eye of cephalopods approaches that of the fish, it is curious to observe that the deportment of the optic nerve strongly resembles that of the compound eye of insects. It swells out into a large ganglion G, which occupies a considerable portion of the orbit, and from this enlargement numerous filaments spread out into that membrane, which, until Owen's more minute description, was regarded as the true retina, but which it now appears should rather be considered as resembling the common retina of the compound eyes of insects, Figs. 115 to 120.

Between the large optic ganglion and the outer part of the sclerotic coat the space J J is filled up by a mass of white substance, the nature of which is unknown, some persons regarding it as fat, others as of a glandular nature. Owen considers it as analogous to the choroid gland of fish, to be presently described, and Cuvier thought it a sort of cushion for the purpose of protecting the nerve from the pressure of the three straight muscles which move the eye-ball.

It will be noticed that there is no true aqueous humor, and that the only cornea is the transparent skin: between this and the lens there is a large cavity K K, which also passes a considerable distance over the sclerotic coat, it is formed by a thin membrane. Curiously enough into this cavity there is a small external opening, through which water can enter, and distend it; thus it may serve as an aqueous chamber.

Vertebrata.—In all vertebrate animals the eyes are two in number, and being formed upon the same general plan as in man, it will only be necessary to give such an account of the condition and modifications of them in each class, as shall form a connected narrative, and explain how the eye is adapted to the varying circumstances of different tribes.

In *fish* the eyes are placed so laterally that except in a few instances, as in the flat-fish, they cannot both be directed to the same object at the same time.* The eyes are lodged in very large sockets, and supported upon a thick bed of watery cellular tissue. The ball is commonly of a much larger size in proportion to that of the creature than it is in quadrupeds, owing probably to the little light the water transmits, and thus a large organ is necessary for the formation of a distinct image, to enable the creature to pursue its prey; for the more voracious the fish, and the deeper the water it inhabits, the larger in proportion is the eye. Figs. 123 and 126 will show the form of the eye. The cornea is very flat, and there is very little aqueous humor, while the lens is large and spherical, or nearly so. A convex cornea would have been exposed to accidental injury, and to continual abrasion by the friction in passing through the water, which being as nearly as may be of the same (and in deep living marine fish of less) specific gravity as the element it is placed in, no advantage in converging the rays of light could possibly have resulted from it; nor would a large amount of aqueous humor have added to its power, this is therefore only just sufficient to allow the iris to float in. The want of these is compensated by the hard spherical lens, which, concentrating the rays to a short focus, necessitates a flat vitreous humor, so that the

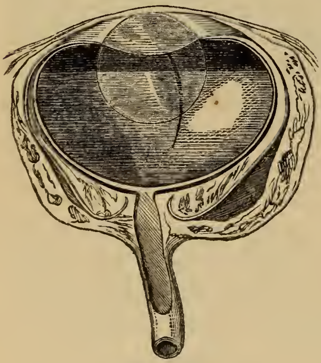

Fig. 123.

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* Such is the general opinion, though I doubt if in some of the narrow-nosed fish, where the eyes are placed forward near the snout, as in some of the salmon species, the little venom-fish, *trachinus vipera*, and other active fish, having a similar formation, an image of an object may not in certain positions be formed in both eyes at the same time.

retina may approach near to the lens, in order that the image may be received upon it.

Though the anterior part of the eye is flat, the sphericity of the posterior is preserved. This is effected by the solidity and density of the sclerotic coat, which is firm and hard, often cartilaginous, containing very little fibrous tissue; and in those which are fibrous, this, towards the posterior part, is of great thickness, particularly in such as are subject to varying pressure, of which the whale affords a good illustration, for though a mammal, and hence probably it preserves its fibrous sclerotic, in its habits and the medium it receives usual impressions through, it is a fish. From the immense depth to which at times the creature descends, the eye must then be subjected to very great pressure, by which, if not crushed, it would be misshapened, and rendered useless. The posterior part is in some an inch and a half thick, while the anterior part is comparatively thin, the strength being where resistance is most required mechanically, and where displacement would most interfere with vision. Figs. 124 and 125 represent two sections of the eye of the whale, the one about the natural size, of which Zinn gave a very good figure, and some good sections are in the museum of the College of Surgeons, London, the other reduced in size is taken from Fred. Cuiver. It shows the lens and cornea in convexity somewhat

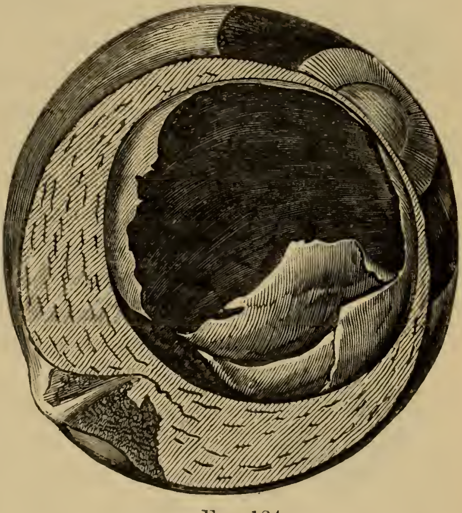

Fig. 124.

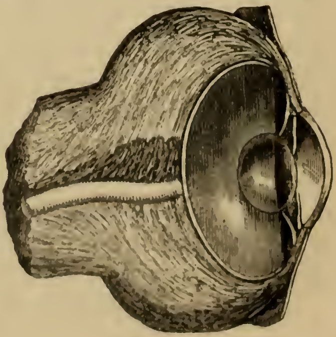

Fig. 125.

approaching those of quadrupeds, and it is worthy of remark that in the whole of these marine mammals the eye is of much less size in proportion to the bulk of the creatures than it is in true fish; indeed in whales it is very small. The mode of obtaining their food upon the surface of the water may explain this. They are not animals of prey, and their size prevents their being preyed upon except by man.

In some fish the sclerotic is encased in a thick cup of hard and dense cartilage, in others there is a thick cup of cartilage within the sclerotic coat, as in the sturgeon; and, again, in other fish, as the sharks and rays, the eye-ball is mounted upon a long and strong pedicle or footstalk of cartilage, by which it is supported and its position maintained, *a*, Fig. 126; between the stalk and the eye-ball there is in the skate a distinct synovial arthrodial articulation *b*. As the optic nerve enters the eye in many fish it is somewhat compressed and folded into flat layers, like a fan, Fig. 127. This is also well seen in the sword-fish, the retina of which retains to some extent the folded condition. The retina extends to the ciliary muscle. Its elements have already been described and figured. They are not so complex as those of mammalia and birds. The choroid coat consists of a distinct double layer, the outer or posterior of which is of a shining metallic lustre; as before mentioned, page 173, it passes to form the anterior surface of the iris, giving the brilliant iridescent character to it. The inner anterior layer is usually dense and black, and forms the uveal surface of the iris. There is a ciliary muscle, but the ciliary body is only imperfectly developed, and the processes are not formed. The pupil is always large and open; it is immoveable and generally circular, though it is easily rendered angular by pressure, and after death it is frequently found irregular in form. In one fish, the Anableps, Sir E. Home says there are two pupils in each eye, which is hardly probable as a normal condition. In Rays there

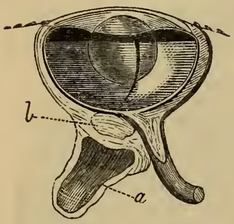

Fig. 126.

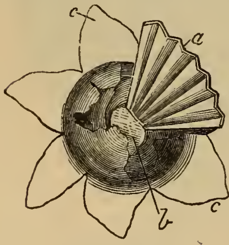

Fig. 127.

is a broad black fringe hanging from the upper edge of the pupil. In many fish there is a thin falciform process proceeding from the retina and choroid, Figs. 123 and 126, and which is well seen in the moon-fish, *Orthagariscus mola.* This body is thought by some to be for the purpose of preserving the lens *in situ,* but it must, I think, rather be regarded as the rudiment of a part more fully developed in birds.

Situated between the two layers of the choroid coat, and surrounding the optic nerve, is a very singular structure, to which the name of choroid gland has been given. It is peculiar to the osseous fish. It is of red colour, of a horse-shoe shape, and surrounds the optic nerve, Fig. 127 *b.** By Home and others this structure was described as muscular, by Grant is called a fatty-body, and by others it has been thought to be erectile, for the purpose of carrying the retina towards and from the lens, and thus to accommodate the eye to vision at varying distances, an opinion which is a mere speculation, and not a very satisfactory one. It certainly is not muscular, and contains little, if any, fat. It is highly vascular, and perhaps contains some few nerves, though not many. It appears to be made up of convoluted blood-vessels, principally veins, and some fibrous structure. The use of it I am unable to conjecture. Hypotheses might be formed, but they are open to so many objections as hardly to be worth naming.

In anguilliform fish, which burrow in the mud, and seek their food rather by the sense of touch than sight, the eyes are usually much smaller than in other fish, particularly the voracious deep-water tribes.

There are neither eyelids nor lachrymal apparatus in fish, both would be useless, the water they live in preserves the cornea moist and clean.

As in man there are six muscles which move the eye-ball; the only difference being that the superior oblique muscle does not, as in him, pass from the back part of the orbit, through a pully at its inner angle, to be reflected backwards to the globe, but like the inferior oblique passes direct from the anterior part of the orbit.

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* Fig. 127 shows the posterior part of the sclerotic, cut open and reflected, *c c c*, to expose the choroid gland *b* surrounding the optic nerve *a*.

Amphibia.—In the perinibrachiate amphibia, as the *Siren*, as the habits of the creature so nearly resemble those of fish, so do the eyes: but in the higher caducibranchiate, as the frog and toad, the eyes, though still preserving the general flattened form of fish, approach nearer to the true air-breathing animal. The cornea is still flat, the crystalline lens is spheroidal, the iris is motionless, the ciliary muscle and body are defined though the processes are wanting, and the sclerotic is firm and cartilaginous, but the choroid gland has disappeared. Eye-lids are now developed; there is even a third, the *membrana nictitans*, moved by its own muscles. The muscles which move the eye-ball in the frog are curious, there are no oblique muscles, and only three straight, but there is one transverse muscle. If a frog be attentively examined and the head or fore part of the body be touched, the eye will be seen to be suddenly depressed, and so soon as the danger is passed again elevated. The mechanism by which the elevation and depression are accomplished is this:—the three straight muscles which surround the eye are attached to the margin of the optic foramen, which is below the eye, consequently when they act together, they pull it within the orbit, which is open to the mouth. The fourth muscle passes directly under the ball like a suspending band, and is attached to each side of the orbit. It is thus put upon the stretch, when the ball is depressed towards the mouth, and no sooner do the three straight muscles cease to act than it comes into play and projects the ball from the orbit. (Fig. 128* shows these muscles.) It may from its position be regarded as the analogue of the two oblique muscles united together under the eye-ball.

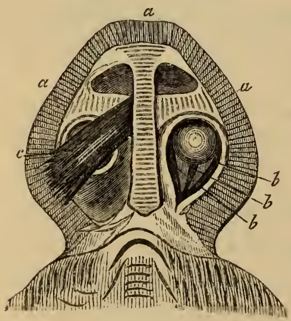

Fig. 128.

The advantage of this contrivance to these creatures is very great; if the eye were permanently elevated, it would have been constantly exposed to injury from the creature creeping into holes amongst stones and rubbish, while if the eye were constantly depressed the field of vision would be so limited that the locomotion of the creature must have been much less.

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* Fig. 128, *a a a* under surface of skull and orbit in a frog; *b b b* the three straight depressor muscles of eye-ball; *c* the transverse elevator muscle.

In *reptiles*, whose habit and organization are more highly developed, but who pass a considerable portion of their time in water, the eye is still further modified, so that it is adapted for vision both in water and air. The cornea is more convex, the aqueous chamber larger, the vitreous humor more abundant, and the lens is less spherical. Within the anterior part of the sclerotic there is often a ring of ten bony plates. The ciliary processes are somewhat developed. The pupil is moveable, generally round, but in some, as the crocodile, the aperture is elongated vertically, or is lozenge-shaped; often there is more or less of a pecten. In serpents there are no eye-lids, the skin passes over the cornea, and is then thrown off with the rest of the epidermis; but in turtles, tortoises, and crocodiles, both eye-lids are well developed and moveable, the lower lid being as large as the upper. There are no cilia on the lids. The *membrana nictitans* is large and provided with a very large gland for throwing out mucus, which facilitates its motions over the ball. Fig. 129 represents a section of the eye of *Emys. Europæa*, by which on comparison with the fish (Figs. 123, 126), its modifications are seen. Fig. 130 shows the ring of ten bony plates found in the sclerotic.

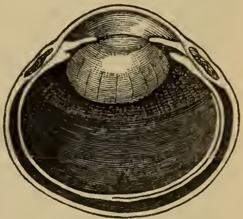
FIG. 129.

The eye of *birds* presents many modifications in accordance with the habits of the creatures and the rarity of the element which they live in, as well as the large amount of light with which this is saturated. Perhaps no animals have such a range of vision. They see distinctly substances in close proximity with the eye, at the point of the beak for instance, and they perceive objects at such an immense distance as to have led some persons to doubt, and others even to deny, the possibility of vision being the sense which informs them of the presence of objects, and to refer it to some unknown faculty, as a sixth sense. Yet observation and experiment lead irresistibly to the conclusion, that to sight alone do birds of prey owe the perception of the distant quarry. Equally surprising with the extent of vision is the

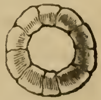
FIG. 130.

power and delicacy of adjustment of the focus of the eye. The osprey and the hawk, while soaring high in the air, sight their prey, upon which they rapidly descend and seize it with unerring precision. With as great rapidity must the aberration of parallax be corrected. So also their exposure to the brilliant sunshine and dark shade necessitates a power of perception in the most varying degrees of light, hence a corresponding delicacy of action in the parts which regulate the amount of light admitted to the retina. To endow the eye, with such powers special structures are either introduced or important modifications in those previously existing are made.

The eyes of rapacious birds present these characters most strongly marked. Figs. 131 and 132 are views in profile of the

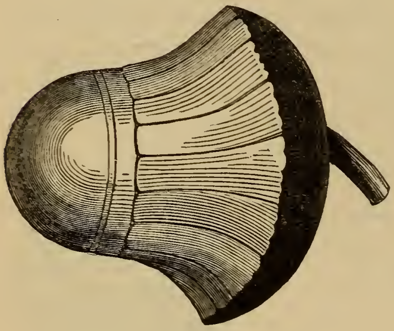

Fig. 131.

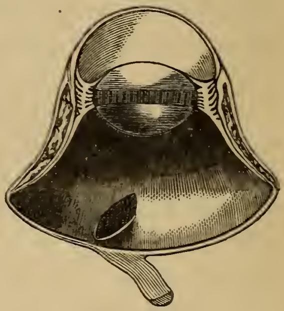

Fig. 132.

eye of the large snowy owl. It will be seen what a strong contrast these present to the flat eye of fish, and even to the spherical globe of man. The posterior part of the sclerotic where the retina is expanded is spheroidal, but the anterior portion is prolonged into a tubular form by the introduction of a bony ring, composed of a series of quadrangular plates, the sides of which are connected together by ligament. The plates are imbricated, overlapping each other, as the slates upon a house do, and the ligament is sufficiently loose to allow the plates somewhat to slide upon each other, yet it is firm enough to prevent any separation. The form and arrangement of these plates are shown in Fig. 131 of the snowy owl and Fig. 133 of the golden eagle, where they are well developed.

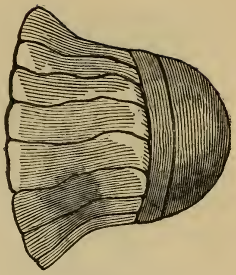

FIG. 133.

The cornea is large, thin, elastic, and very prominent (Figs. 131, 132, and 133), the aqueous humor is very abundant, as compared with that in fish. We have seen that the crystalline lens is flat, and its density is less, but more uniform. The vitreous humor is copious and abundant, so that the retina is expanded at a greater distance from the lens, and the whole axis of the eye is elongated. The iris is very active, it is capable of contracting the pupillary aperture to a mere point and of suddenly expanding it to a large size, and that by volition, for the opinion long entertained by some observers, of the voluntary motion of the iris, has been confirmed by the discovery of striated muscle in the iris of birds, the nerves going to it are large. The anterior surface of the iris is most varied in colour, and of great brilliancy; its posterior surface is thickly covered with dense pigment, with which the choroid also is deeply imbued. The ciliary muscle is strong, and the ciliary body and processes are largely developed. In the posterior part of the eye of birds is a most remarkable structure, the *pecten or marsupium.* This is a dense black falciform or irregularly quadrangular process, which proceeds from the outer side of the entrance of the optic nerve; it extends from the choroid through the middle of the vitreous humor as far the crystalline lens to which it is attached. Fig. 134. This body consists of a number of folds, varying from four in the goatsucker, *Caprimulgus Europæus,* to nearly thirty in many singing birds. The folds may be expanded into a membrane. Figs. 135 and 136. It is densely covered with black pigment. In a very rudimentary condition the pecten is found in some fish and a few reptiles, otherwise it is peculiar to birds; as might be expected from its situation, the presence of so large and black a body in the centre of the eye, where it cannot but obstruct a large number

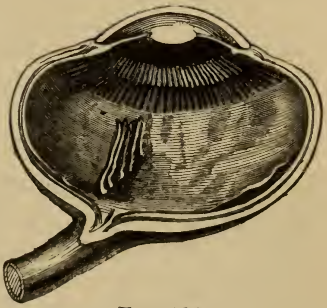

FIG. 134.

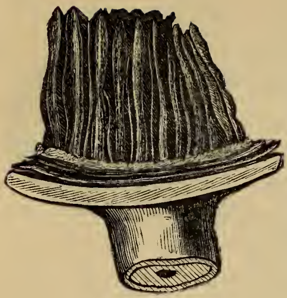

Fig. 135.

of rays of light, has given rise to many speculations. Some persons have thought it to be merely for the purpose of conveying blood-vessels to the lens; an opinion not at all probable, or why of so large a size and peculiar to birds? Others have considered that it is for the purpose of moderating the quantity of light admitted to the eye, which is scarcely more plausible than the former opinion, as there is already the active dark screen—the iris, for effecting this. Sir E. Home, who propounded some rather strange notions in physiology, supposed the use of the pecten to be for dividing the eye into two compartments as it were, the one for perceiving near objects, the other more distant. That the pecten is subservient to accommodating the eye to vision at varying distances is highly probable, but it is most improbable that it should be so in this manner.

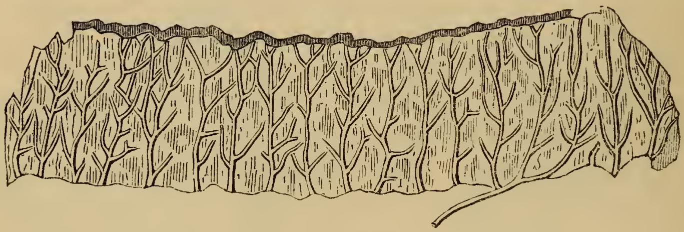

Fig. 136.

It is highly vascular, and when examined under a high power and well teazed out it is seen, besides blood-vessels and the dense black globular pigment resolvable into minute cells as in the choroid, to consist of fibres as that coat, and of an elastic structureless substance much resembling the suspensory ligament of the lens, and the elastic lamina of the cornea. The blood-vessels are continuous with those of the choroid. There are few if any nerves, and none of the retinal element upon it, pl. IV. fig. 10, though it is stated by some anatomists that the retina is continued

Fig. 135, magnified section of eye of goose, to show the position of the pecten. Fig. 136, the same unfolded.

upon it, and after the eye has been kept in spirit, on a cursory examination such may easily be supposed to be the case, both in birds and fish. See prep. 1648, the eye of the moon-fish, in the College of Surgeons, London. May the pecten not be an opponent of the ciliary processes and iris? If we suppose that in distant vision the ciliary processes are distended and allow the lens to recede, the pecten may be thought not to be in a turgid condition, when its elastic structure would draw the lens towards the retina, but when near objects are regarded, the vessels of the pecten may become turgid and the process lengthened, while the contraction of the iris and lessened ciliary processes would pull the lens forwards, or at least allow of its passing forward in the general elongation of the axis of the eye by the pressure of the external muscles.

The whole structure of the eye of birds shows an adaptation for greater changes in its optical parts than is seen in other creatures; the lens is as it were hung between two elastic bodies, the pecten and the ciliary processes. The firm tubular, yet yielding, anterior sclerotic coat, the thin convex cornea, and the abundant aqueous humor, all tend to show a delicate and varying power of adjustment without the necessity for the small circular muscle which some anatomists think they have seen attached to the margin of the cornea, and which is shown in Figs. 132 and 133, or that which Home described as passing from the lens to the vitreous humor.* In birds who shun the sun-light and seek their prey by night there is an absence of the choroidal pigment. They are albinos, and hence the red colour of the choroid is seen through the pupil.

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* Corneal Muscle. This muscle which was first described by the late Sir P. Crampton, and has since been called after him, by those anatomists who have recognised its presence, has been supposed to be peculiar to the cornea of birds. This, I doubt, and also whether there really be any distinct muscle attached to the margin of the cornea. Not that any doubt can exist as to the presence of muscular fibres in this situation, for they are readily enough found. I incline however to consider them as portions of the iris and ciliary muscle where these structures are strongly attached to the corneal margin; more distinct and easily recognised in birds than in mammalia, because the fibres in the iris and ciliary muscles in birds are stronger and are striated like the muscles of the heart, but not peculiar to them, for on carefully examining the margin of the cornea in mammalia in precisely the same situation, fibres of unstriated muscle, like that of the iris and ciliary circle in mammalia, may also be detected. The attachment of them to the cornea being the most fixed point I should incline to think whatever action they may have would rather be upon the iris and ciliary body than upon the cornea.

As the habits of birds differ much, so does the form of the eye. In the rapacious, it is as now described, but in those birds which pass most of their lives upon the water, and often obtain their food under it, the eye is much flatter and the bony sclerotic plates not nearly so tubular. Compare the eye of the goose, 134, with those of the owl and eagle, 132 and 133. Such birds often obtain their food rather by the sense of touch in the bill than by distinctness of vision. Their eye more resembles that of reptiles.

The eye-lids are fully developed, and very moveable, the lower lid is larger and more active than in quadrupeds, being provided with a distinct muscle, as the upper alone is in them. There are four straight ocular muscles, and two oblique; both of which arise from the anterior part of the orbit, there being no pulley for the superior oblique.

Birds moreover are always provided with a third eye-lid—*membrana nictitans*—which though not peculiar to them, as it is possessed by reptiles and many quadrupeds, yet being in birds so constantly found fully developed, its description is most appropriately here placed.

It is always found at the inner angle of the eye, and when not projected is so far withdrawn as to be hardly visible. It is rapidly drawn across the cornea, and as rapidly, or more so, withdrawn. The free edge of it is thin, sharp, and almost horny. The inner or attached is thicker, and merges into the cushion, upon which it is placed. This cushion consists of fat globules, and yellow electric tissue, by which the membrane is drawn out of the way the moment the muscles cease to act. The membrane is sufficiently transparent to allow some light to pass through it; and birds, when in a strong sunlight, will often sit in a half sleepy state, and allow it to remain for some time over the cornea. Fig. 137 shows the membrane extended half over the cornea. The projection of the membrane is effected by two muscles, called, from their shape, the quadratus and the pyramidalis. (Fig. 138.) The first is attached to the sclerotic coat above the cornea, it passes backwards to the optic nerve, where it abruptly

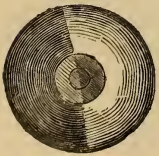
Fig. 137.

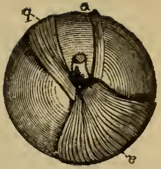

Fig. 138.

terminates in a tubular tendinous loop, without any distinct fixed attachment. The pyramidalis is a small musclewith a long tendon. It is attached to the fore-part of the sclerotic coat, near the inner margin of the cornea, it runs outwards and backwards as far as the optic nerve, round which it suddenly turns to pass to the inner angle of the eye, when it joins the lower part of the membrana nictitans. As it passes round the optic nerve it becomes tendinous, and this small round rope-like tendon runs through the pulley in the quadratus muscle. As the two muscles act together in projecting the membrane, not only is the power of the pyramidalis considerably increased by the opposite direction in which the quadratus pulls, but it is rendered more rapid by the combined movement, and at the same time the tendon of it is braced away from the optic nerve, which otherwise would be pressed upon at each contraction of the muscle, whereby sight would be injured if not permanently destroyed.

Birds have, as reptiles, a large Harderian gland, which pours out a large quantity of lubricating mucus, for facilitating the motions of the third eye-lid across the cornea.

The lachrymal apparatus exists in birds as in quadrupeds.

The eyes of *mammalia* in all essential particulars so entirely agree with those of man that only a general glance at their modifications is necessary. Those which inhabit the water have, in proportion as their habits are aquatic, the eye approximating to that of fish. The eye of the whale has already been spoken of; to some extent the same condition prevails in the eye of the seal. The cornea is flatter, and the lens more spherical, while the posterior part of the sclerotic is thicker than in the higher quadrupeds.

In the rodentia and in the smaller and timid herbivora, such as feed at night, and are preyed upon by the carnivora, the eyes are larger and placed laterally, while the larger and stronger of herbivorous creatures, and the pachyderma, as the elephant, rhinoceros, and hippopotamus, have a small organ of vision. In

Fig. 138, eye of bird. *a*, the quadratus muscle; *b*, the pyramidalis; *c*, its tendon.

carnivorous animals, particularly the nocturnal, the eyes are large and prominent, and less laterally placed in the head, so that they can be more directed towards the same object, an arrangement which also prevails in nocturnal birds.

In those creatures whose habitation is for the most part under ground, as the shrew and the mole, the eyes are so small as to have led Magendie to assert that the mole is without the organs altogether, which is not the fact, for I have found all the essentials of an eye, even true retinal elements, optic nerve, and a well-developed choroid. Yet the organ is so minute and concealed by the skin and hair, as probably only enables the creature to discern the light, which is all that it requires, for living under-ground where it seeks its prey, it obviously must depend upon the acuteness of other senses than of sight for its living.

Though in the individual there is usually some proportion between the size of the eye and the body, taking different classes and genera, the size of the animal is very little guide to that of the eye, the proportions between the two being determined by other considerations than that of the bulk alone of the creature; for though as a whole the eye in fish bears a larger proportion to the whole body than it does in other divisions of the animal kingdom, and the eyes of birds are, as a class, much larger than those of mammalia or reptiles, yet amongst the different genera of all these classes there are very great differences, determined apparently by the following considerations amongst others not so obvious.

Where the creature lives in a feeble light, yet moves actively about, and is guided in its locomotion by the sense of sight, as in nocturnal birds and animals and in fish, in the eye is very large, apparently to take in a large quantity of the feeble light: on the contrary, where the creature is guided in its movements by other senses, then the eye is very small, as in the mole, the shrew, and the eel.

Where vision penetrates to a long distance, and where the eye enjoys great power of overcoming the aberration of parallax, the eye is large, as in birds.

When the brain and intellect are more developed the size of the eye diminishes and the two eyes become more parallel, as in man and the higher mammalia.

Where animals are feeble, timid, have but little defensive power, and are preyed upon, the eye is usually very large, as in the hare, the cavia, the whole deer tribe, and many of the other ruminants.

Where the animal is not predacious, and its size and strength are such as to protect it from being preyed upon, the eyes are commonly small, as in the whale and the elephant : in the latter the eye is even smaller than it is in the horse and scarcely larger than in the eagle.

As we pass from fish through reptiles, whales, dolphins, walruses, seals, otters, and beavers, the cornea is found gradually to become more convex, and the crystalline less so, the coats of the eye thinner, and the ball more spherical: so also is the position of the eyes altered, it gradually becomes less lateral, until in the quadrumana the eyes are nearly parallel in their direction, and in man perfectly so. This appears to be a thing of much importance, and apparently is intimately associated with the development of the intellectual faculties.

All mammalia with the exception of the purely aquatic, to whom it would be useless, possess a lachrymal apparatus, and all quadrupeds possess the same orbital muscles as man. In addition to which, the larger, which have the head hanging downwards for a long time in grazing, as the bullock and sheep, have another large strong muscle. It is interposed between the four straight muscles and the optic nerve, which it surrounds like a hollow cone. It passes from the optic foramen to the sclerotic coat; but it is attached so near to its posterior part that it can exercise but little influence over the rotatory motions of the ball, it will powerfully support or draw the globe within the orbit. It is called the suspensory, circular, orbicular, funnel-shaped, or choanoid muscle.

CHAPTER VI.

ON THE EYES OF FOSSIL ANIMALS.

A WORK like the present would be imperfect without some allusion to the structure of the eyes in fossil creatures, since it is not the least curious nor important chapter in the world's history which is revealed to us, by finding the organs of vision in so many of them preserved so perfectly, as to enable us easily to make out even the details of their structure. A few illustrations will be sufficient for our purpose.

It will not be necessary to refer to the form of the skull and the orbit found in the remains of quadrupeds, inasmuch as they do not differ from those of animals now living, they are familiar to everybody. Those however of the large saurians, the predecessors of our crocodiles, iguanas, and lizards, where the remains of the eye are often wonderfully preserved, are objects of great interest. Fig. 139 represents the head of an *ichthyosaurus,* in which will be noticed the enormous size of the orbit, which in the full-grown creature, is not less than fourteen inches in diameter, forming a cavity vast enough to lodge an eye larger than a man's head; and that this cavity is nearly filled with a series of quadrilateral plates, which form a ring with a central circular aperture. These can be no other than the sclerotic plates, identical with those of reptiles now living, as in the

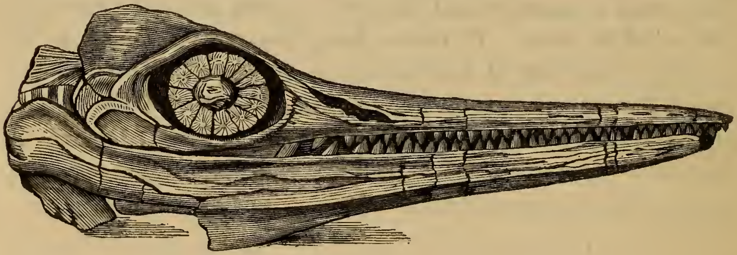

FIG. 139.

tortoise, figs. 129 and 130, and particularly in the nearest living representative,—the iguana, shown in Fig. 140; in which *a* is a front, and *b* a profile view of the sclerotic ring in this creature. Fig. 141 represents, *a*, two of the separate plates in the eye of the ichthyosaurus platyodon, and *b* two plates from the eye of the iguana.

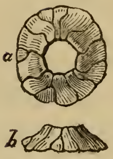

Fig. 140.

Large as is the size of the orbit, on the authority of Dr. Buckland, as fourteen inches in the *icthyosaurus platyodon*, it is considerably exceeded, in proportion to the size of the entire creature, in the head of an *ichthyosaurus tenuirostris* now before me, in which the entire side of the head appears an orbital cavity. From the extreme outer surface of the occipital bone to the nasal opening is only six inches, while the orbital cavity (within measure) is fully five inches: from the vertex to the upper edge of the lower jaw, is five and six-eighths inches, while in this direction the orbit is four and seven-eighths inches across. The sclerotic plates are beautifully distinct; they form a complete ring, and their enormous size, of an inch and a half, from the outer to the inner edge, proves that the size of the eye-ball must have corresponded in magnitude with that of the orbit. In another head, of the *ich: communis,* where the plates are particularly distinct, in the central aperture of the ring, there is a globular projection, in the position, and of the size, we may presume the crystalline lens to have been, whether it be the actual vestige of it I will not venture positively to assert.

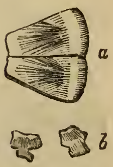

Fig 141.

Such a structure of eye proves that the ichthyosaurus was adapted both for land and water. The eye was formed to receive impressions through air and water. The size of its eye was enormous, far exceeding that of any living creature. In this respect it more resembled the predacious fish, which live in deep water, than any other creature, doubtless for the same reason, that it pursued its prey at the bottom of the bays and estuaries which it inhabited, and therefore was the eye enormous to take in a large amount of the feeble light that could penetrate to its habitation, overshadowed as this probably frequently was by a thick luxuriant vegetation.

But if we go farther back to a period antecedent to the existence of even these antediluvian creatures, we are still more surprised to find amongst the earliest fossiliferous remains, even of animals which probably had ceased to exist prior to the formation of the ichthyosaurus, and whose remains are not found subsequent to the carboniferous strata, well-preserved compound eyes, identical in structure with those of living crustacea, as a comparison of three creatures, one that ceased to exist perhaps untold ages ago, one that lived when coal was in process of formation, and still survives in abundance in the warm Indian and American seas, and a more recent congener now living, will show. Fig. 142 represents a Trilobite, the *Asaphus caudatus,* in which the position and general form of the compound eyes are well marked; and Fig. 143 is a magnified view of one of these eyes through which the primeval light of heaven was enjoyed by these, if not earliest of beings, at any rate amongst the earliest of animals.

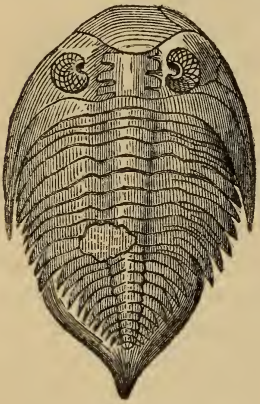

Fig. 142.

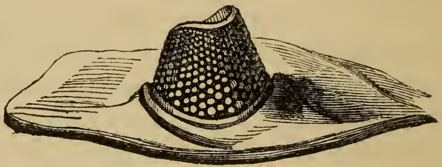

Fig. 143.

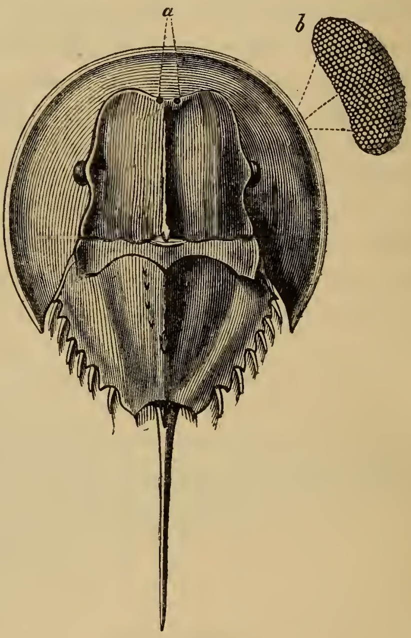

Fig. 144.

Fig. 144 is a *limulus* or king's crab, which in structure and habits presents a close approximation to the *asaphus*. In this creature the compound eye is not much elevated and cannot command the space immediately in front of the head; here, therefore, as in many insects, and similarly placed, are found two simple eyes *a*: *b* is the compound eye magnified to show the hexagonal facets. Fig. 145 is the *Branchipus stagnalis*, which inhabits our ponds. In some parts of its organization it is said to present strong resemblance to that of the trilobites, but it is more active in its habits, and moves with considerable rapidity, it, therefore, requires a wider range of vision than an animal which slowly crawls upon the bottom. The eye of the Branchipus therefore is placed upon a peduncle, and is nearly hemispherical. *a* is the simple eye, *b* the compound eye, *b′* view of the same eye magnified.

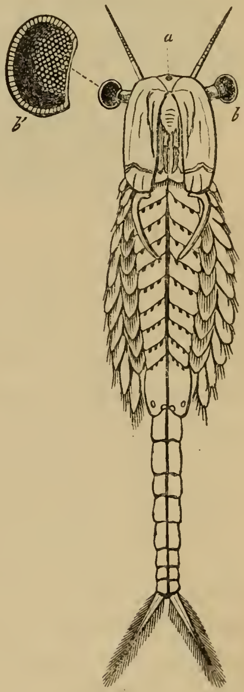

Fig. 145.

In the Asaphus caudatus, Figs. 142 and 143, each eye contains at least four hundred facets or separate compartments of the cornea, and the form of the whole is peculiarly adapted to the case of an animal destined to live at the bottom of the water, as this creature was. To look downwards was as impossible as it was unnecessary, but for horizontal vision in every direction the contrivance is complete. The form of each eye is nearly that of the frustrum of a cone, incomplete only on that side which is directly opposite to the corresponding side of the other eye, and in which if facets were present, their chief range would be across the head, towards the other eye, and the space which it commanded. It will be recollected that an exactly similar absence of facets was pointed out in the eyes of the shrimp, Fig. 111, and other allied living crustaceans, and which is doubtless to be accounted for in similar way.

The exterior of each eye in the asaphus, like a circular bastion, ranges nearly round three-fourths of a circle, each eye commanding so much of the horizon, that where distinct vision of one eye closes, that of the other begins, so that in the horizontal direction the combined range of both eyes was panoramic.

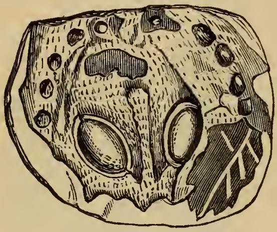

Fig. 146.

Fig. 146 is the figure of the head of a fossil scorpion, found in the Bohemian coal formation, and completes the link in the chain, for here are found eye-dots of precisely the same character and form, and in the same position, as are seen in scorpions of our own day, as comparison with outline Fig. 103 will show. The ancient scorpion, however, was like many of the then existing creatures, of very much larger size than the congenerous animals of our day. Other illustrations might easily be given, but these are sufficient. They show us not only the habits of the creatures, but the condition of the air, the water, and the light of the then world. The voracious ichthyosaurus, though air-breathing, passed its time in the water, and obtained its food in the depth of it; lying probably basking on the surface of the water, or lurking on the overgrown and shaded margin of the pool or estuary, almost concealed from the light of day by the mass of luxuriant tropical foliage. The asaphus slowly crawled upon the mud on the bottom of the sea. The water then generally must have been limpid, turbid probably at times, but certainly not invariably thick and muddy. The large scorpion had eyes as those now living have; it must have had similar habits, and have seen in the same manner as those of our day; therefore the atmosphere in that ancient world could not have materially differed from its present actual condition. We know how greatly a fog or mist now obscures the light; it must have been so then, and hence the inevitable inference, that the atmosphere was for the most part clear and transparent. The sun must have shone in radiance and not have struggled in dim twilight to disperse a dense mass of thick watery vapour. That light was the same then as now, these remains render certain. We have seen that there are but two modes in which an apparatus can be formed, by which the image of an object can be obtained, and also that both of these methods are taken advantage of in the construction of the eyes of living creatures.

The revelations of geology have shown that the same arrangements have prevailed in congenerous creatures *ab initio.* If the instruments have always been the same, the laws of the medium through which sight is obtained must also have been so, since the instrument is, and always must have been, formed in accordance with these laws. Such reasoning would open a most interesting and important chapter in the world's history, but it would lead us too far from our immediate inquiry.

CHAPTER VII.

ON THE PHYSIOLOGY OF VISION, AND A CONSIDERATION OF SOME OF THE PHENOMENA CONNECTED WITH IT.

UNDER the head of Physiology of Vision, I propose to consider several of the more important and interesting questions which arise during an examination of the structure and functions of the eye. Some of these are phenomena of a purely physical character, common alike to the eye and all dioptrical instruments, as chromatic and spherical aberration: others have nothing in common with any mere optical apparatus, they are entirely of a vital character, and are functions of the structure of the eye, and those parts of the sensorium in relation with it, as parts of the living body; as single vision from two images; erect vision from an inverted image; complimentary or accidental colours; ocular spectra; while again, others may be considered as partaking of both a physical and vital character, as the position, motions, and use of the iris, and accommodation of the eye to different distances.

It is not a matter of very great importance in what order these questions are taken, inasmuch as several of them are not very intimately connected with each other, so long as those which present some similarity or relationship are consecutively considered. The aberrations or defects, as they are not unfrequently called, which are common to the eye and dioptrical instruments, having so frequently been mentioned, may first claim our attention; a position which their importance to correct vision also entitles them.

It will be recollected that it was stated there are three principal difficulties to be overcome in the construction of optical instruments, aberration of parallax or distantial aberration, spherical aberration, and chromatic aberration, which in Chapter

III. were referred to in the order here mentioned. At present it will be more convenient to reverse it, and to take aberration of sphericity first, which, though so serious a difficulty to the optician, is most simply and beautifully overcome in the eye, while the two others, and particularly distantial aberration, are subjects of such great complexity as, not merely to have led to very various opinions, as to the manner in which they are overcome in the living eye, but to have caused some of the greatest authorities, both physiologists and opticians, to deny, though erroneously, that they are overcome in the eye; and, hence, they require a more careful investigation.

Aberration of Sphericity.—The great difficulty which the nature of light in its refraction through curved transparent bodies presents to its rays being accurately collected into a focus, and the absolute necessity for this being effected before a perfectly defined image of any object can be formed, as well as the elaborate and ingenious contrivances by which opticians have at length been enabled to overcome it, have been sufficiently explained at page 73, and the simple, and far more perfect and beautiful, because more simple, manner in which this object is effected in the eye, by the correspondence between the lesser obliquity and greater density of the axis of the lens, and the greater obliquity and lesser density of the margin of it, has also been fully detailed at page 77; to repeat which here would be useless. It only need be said that the aberration is completely overcome in the crystalline lens.

Chromatic aberration.—It will be recollected that this serious difficulty in the construction of optical instruments arises from light consisting of variously coloured rays, which possessing different degrees of refrangibility, in passing through a transparent refractive medium, are bent unequally, and hence the formation of variously coloured images from white light. This matter like the last has also been referred to in Chapter III., at page 77, and the great difficulty which opticians have had to contend with, and how they have overcome it, explained. So great indeed are these difficulties that some opticians, who have had to contend with them, have been of opinion that the construction of the eye is too simple to be achromatic.

Dr. Maskelyne instituted many experiments and many most elaborate calculations, from which he drew the inference that the eye is not perfectly achromatic. Dr. Wollaston also thought the eye could not be perfectly achromatic, and Sir D. Brewster not only says that the idea of the eye being achromatic is founded upon an imperfect analogy, but declares that "the non-achromatism of the eye is a fact as well established as any of the facts in natural philosophy." The opinions however of Maskelyne and Wollaston were founded upon experiments, the accuracy of which other observers, repeating with every care, have failed to verify, and do not coincide in; and some of the statements and the deductions drawn from them are palpably wrong, while other mathematicians of at least equal celebrity, as Professor Powell have shown by as learned calculations and reasoning, that such a combination of lenses as, even according to their measurements, exists in the eye, may, on the strictest principles, be perfectly achromatic.

That the eye is practically achromatic no one can deny, and, while I would not be understood as undervaluing theory, or as not being fully alive to the importance of mathematical calculations, I must be allowed, before I am called upon to admit as indisputable the conclusions drawn from them, in opposition to every day's and everybody's experience, to ask that some unexceptionable and certain data be secured as their basis. This is not the case in the present instance; one of the most important suppositions, which has been much relied upon, that curves refracting the rays of light all in one direction cannot from their very nature be achromatic, has been proved to be erroneous. It has been shown and is, I believe, now generally admitted as a fact, that it is possible for rays all being refracted in one direction to emerge colourless. While Professor Powell has satisfied himself by calculation, that with lenses of such a curve as are assumed to exist in the eye this would be their effect. But in this inquiry there has been too much assumption and too little proof; the measurements which have been relied upon have been rather assumed to be correct than shown to be absolutely true.

Considering that very minute differences produce such very different results, and the extreme difficulty, even with every wish and desire to be so, of being absolutely correct in the measurements of any one eye, and also knowing, that not unlikely this individual eye may differ from most others in its exact curvatures, and also that it does differ from itself at different ages, I cannot in such speculations, which from their very nature are so liable to error, give up experience, rough though that may be, for speculation, however learned and refined it may be. Besides, there is another circumstance which though of great weight, has been but very little, if at all, attended to. It has been imagined that the dispersive powers of the different parts of the eye were correctly known and allowed for in the calculations: now this is by no means certain or even probable. It was Newton's assumption of the uniform correspondence of the dispersive and refractive powers of different substances, that led him to the conclusion of the impossibility of chromatic aberration in optical instruments ever being overcome. This we have seen, and the means by which it has been effected, to have been perfectly accomplished: now there is nothing unreasonable or unphilosophical in the supposition, which I hazard, of the different structures in the eye possessing such different dispersive powers as exactly to counterbalance each other, and cause the rays to fall colourless upon the retina. On the contrary, I believe there is every reason to conclude such to be the case, and that the varying curves and densities of the different media of the eye are such as may fairly be supposed to be able to correct each other. The fact that they by some means do so experience shows to be undeniable, however much according to the assumed data they may be unable to effect this.

The eye must be regarded as a compound lens, far more complicated than any triplet yet made is—first, there is the cornea, with its convex anterior and concave posterior surface, with the three dissimilar textures of which it is made up,—the epithelial, the fibrous, and the structureless elastic layer: next the aqueous humor with its convex anterior and concave posterior surface: then is placed the lens with its two convex, yet most unequal, surfaces, and lastly there is the concavo-convex vitreous humor. These lenses have all different densities. The difference in their densities, I am aware, are not great, but then only very slight differences are required, according to the best mathematical formula, to produce an achromatic effect. This is on the assumption that the precise dispersive power of these various parts is absolutely ascertained and calculated for. But this is by no means the case, for it appears to be highly probable, that as it is known that different bodies, irrespective of density, are endowed with very different dispersive properties, so this may occur with the different structures of the eye. It is by no means certain that the strong elastic anterior capsule of the crystalline lens, and of the posterior elastic lamina of the cornea, may not have very different dispersive power, as compared with their refractive, than a mere calculation of their density would show. We know this to be the case with many substances, the diamond for instance, and to say the least, there is no greater impropriety in my assuming this to be so, than in others assuming it not to be so.

Besides, may not the crystalline lens be endowed with the same property of correcting the aberration of colour as it undoubtedly possesses as regards that of sphericity? The amazingly complex structure of the lens must be for some important end, and it is not impossible this may be one means of rendering the eye achromatic: at all events we are fully justified in declaring the fact of the achromation of the eye, though the precise means by which it is rendered so may admit of dispute.

Aberration of parallax, or distantial aberration.—It is obvious that in the formation of an image from any object, the eye, like all other dioptrical instruments, will vary in the length of its focus, according to the direction of the rays of light, whether they proceed from a near or distant object. This effect will be more readily understood by referring to page 71, and to diagrams 39 to 41. This aberration to the optician is a mere trifle to the two preceding errors, as he can readily overcome it by so constructing his instrument, that the lens admits of being carried nearer to, or farther from, the surface intended to receive the image, according as the object itself may be more or less distant from the lens. That some corresponding power exists in the eye is certain: were there no such power of adjustment objects could only be distinctly seen when placed at one uniform distance from the eye, but we are all conscious of having the power of accurately examining objects when placed at very different distances, it is, however, by no means so evident in what this power consists.

Thus, suppose two small objects as two pins are placed before one eye, the other eye being closed, and one of these pins be at six inches distance, the other at six feet, if that at six inches be distinctly seen, the one at six feet will be indistinctly seen, and if the distant one be looked at, so as to be clearly seen, the nearer object will become confused; both cannot be accurately seen at the same time, we can cause the one or the other to be distinct as we please by a voluntary effort, and of this effort we are conscious: if the image of the near pin be distinctly thrown upon the retina, that of the distant one will pass beyond it, and if that of the farther one be thrown distinctly upon the retina, the image of the near pin will not reach it, so that vision is confused. Since either of these pins can at pleasure be seen distinctly, but not both at the same time, it follows that we possess a power of at will altering the focal length of the eye, and adapting it to objects at different distances. So also, as Porterfield remarks, such a power must be possessed by birds that pursue their prey both in the water and in the air, for the variation in the refraction in the two media is equivalent to very different distances of the object in one of them.

There are many circumstances which materially modify the distance at which any object can be distinctly seen. Thus the larger the object, the greater is the distance at which it can be seen, the more brightly it is illuminated the farther off will it be perceptible; the colour of it and also the colour of the surrounding objects which contrast with it make an important difference, as may be easily shown by placing in succession pieces of paper of the same size and shape, but variously coloured, upon a painted wall, when it will be found that at a distance at which some of the coloured papers can scarcely be discerned, others are perfectly distinct. Again the shape of an object, and whether it be in a state of rest or of motion, influence the distance at which it can be distinctly seen. The sportsman well knows that he can recognise a bird in motion on a moor at a much greater distance than one sitting still.

For most eyes under ordinary circumstances, the eye being in an easy state without any effort, objects are best perceived at a distance of from ten to eighteen inches, according to their size, but when small objects are minutely examined they will be brought nearer to the eye—seven or eight inches, and many persons can see distinctly at four or five inches. With an effort, I can for a short time see at two inches distance, but this only by an effort, which very soon becomes painful. There is a difference of opinion as to the distance at which objects can be seen, the estimates being very wide, but supposing the eye can collect into a focus rays which are nearly parallel, which probably the majority of eyes can, it is evident no definite limit can be assigned to vision, though in this respect a great difference exists in different persons, some can see distinctly only within a short range, while other persons can see at a much greater distance. The former are said to be myopic, the latter presbyopic. Children and young persons are more usually the former, older persons the latter. The causes of this difference, and the means of correcting it, will be referred to hereafter.

Though the great names of De la Hire, and Haller, Magendie, Simonoff, and Treviranus, may be quoted as amongst those who have asserted that the eye does not possess the power of accommodating itself to different distances, it so necessarily must and does possess this, and the proof of it is so easy, as in the simple experiment just described, that very few, if any, persons would now hesitate to allow that the eye is endowed with the power, but there is by no means the same unanimity as to the means by which the adjustment is effected. On the contrary probably no investigation has given rise to more speculation, to more experiments, or to a greater number of learned calculations, with less satisfactory proof as a result of the labour bestowed, than this inquiry. This indefinite result to a considerable extent, perhaps, admits of explanation.

For distinct vision it is certain that the image formed by the refracted rays must fall accurately upon the retina. When the rays are nearly parallel, as when they come from a distant object, a certain degree of refraction will collect them into a focus at a certain distance behind the lens: but if the rays are very divergent, as from a near object, the focus will be more remote. Hence the distance between the lens and the retina must be capable of being lessened or increased; the refractive power of the eye must admit of variation, by a difference in the curvature of some one or other of its parts, or by an alteration in their density; or there must be a combination of some two or more of these changes to effect the adjustment.

In order to understand the opinion which I shall advance as that which appears to be the most probable mode of explaining the change of focal length in the eye, it will be necessary to allude to at least some of the more plausible opinions which have been entertained. A volume might easily be filled upon this subject alone, such importance and interest have mathematicians and physiologists attached to it. They may be enumerated under the following heads:—

1st. That it depends upon the motions of the iris.

2nd. That the cornea becomes more or less convex.

3rd. That the refractive power of the lens is altered by a change in its curve.

4th. That the position of the lens is altered, it being pulled forward or depressed towards the retina.

5th. That the axis of the eye is shortened and elongated.

1st. When describing the structure of the iris it has been shown how it acts as a stop or diaphragm, and also that the size of the pupil varies according to the distance of the object under examination. When a near object is viewed the pupil is contracted, when a distant one it is dilated, and this change occurs independent of volition. Hence some persons have been inclined to think, that it is upon this change alone in the size of the pupil that the adjustment depends. This was the opinion of the celebrated De la Hire, and more recently of Treviranus. That this change is one of the means is certain. The examination of a near object through a pin-hole in a piece of blackened cardboard, will at once show how the exclusion of the more oblique rays renders the image more distinct; but this cannot be the sole means, inasmuch as the degree of contraction in the iris and the size of the pupil are not in *constant* relation to the distance of the object examined, nor solely dependent upon it, but are also regulated by the degree of light. Indeed, it would appear that the degree of light rather than the obliquity of the rays is the immediate cause of the variation in the size of the pupillary aperture. Everybody knows how sensitive the pupil is to varying intensity of light, even when no particular object is regarded, and as, *cæteris paribus*, the number of rays which are reflected from an object into the eye, is in proportion to the distance of it from the eye, it follows that if, as we know to be the fact, for the production of a distinct impression upon the retina, a certain degree of illumination of the image is essential, that when a distant object, from which the light is feeble, is regarded, the pupil must be proportionally more dilated than when a near object from which the light is intense is looked at, so that the greater number of rays which enter the eye from it may compensate for their lessened intensity. That this is the real cause of the contraction of the pupil when a near object is examined, and not the mere exclusion of the more oblique rays, is proved by looking at the same object at the same distance both when it is intensely and feebly illuminated; in the first the pupil will be more contracted than in the last, yet the variation in the light must solely be in its intensity, and not in the obliquity of the rays, which must be the same in both cases. Besides, this hypothesis of De la Hire can be altogether disproved by a little modification in the experiment of the two pins held at different distances from the eye, for if it be repeated while a card with a pin-hole in it is held close to the eye, so that the two pins can be observed through this hole, it will be found that the eye has the same power of adjusting itself, so as to see distinctly either pin, as it possesses without the screen. Now as the pin-hole is smaller than the pupil, it is evident that in this experiment distinct vision is not effected by changes in the dimensions of it. Though we may therefore admit and appreciate the importance of changes in the size of the pupil, it cannot be the only means; for with a very varying pupillary aperture, the distance being the same, objects are distinctly seen, which could not be the case were the adjustment dependent solely upon the size of the pupil.

The high degree of organization of the iris, and the intimate connection which it has with other tissues, shows its relation with them, and the importance of its functions, but it cannot prove that the adjustment of the eye to different distances results alone from movements in this structure, as De la Hire contended for.

2nd and 3rd. That the cornea becomes more or less convex or that the refractive powers of the lens alters. Each of these propositions has found warm supporters, who have appealed to experiment and calculation in support of the truth of their opinions, while others who have adopted another opinion have in as confident a manner, on the faith of experiment and calculation, denied the possibility of the adjustment being so effected. That adjustment depends upon either of these changes exclusively, it would probably be more easy to disprove than to prove that it does; in fact it must be admitted that the experiments and calculations of Dr. Young satisfactorily show it is impossible for the cornea to vary sufficiently in its curvature to produce the necessary variations in its refractive power; and thus, they in a great degree lessen the value of the experiments of Ramsden and Home in support of the opinion that the change in curvature of the cornea is the cause of the adjustment. While the calculations of Dr. Young* as to variations in the form of the crystalline lens effecting the adjustment of the eye, are still more completely set aside, by the disproval of the opinions which he had adopted as to the nature of the lens, which he supposed in common with several other persons, as Hunter, (who about that period contended for the honour of the discovery) to be muscular. This, not only the chemical analysis of its composition, but still more the microscopical demonstrations of its structure, completely disprove. The crystalline lens does not present one point of resemblance—anatomical, physiological, or pathological, with muscular structure, and therefore analogy between the two cannot be appealed to. I must also confess that I do not place much dependence upon calculations and measurements which have been made with so much care and ingenuity by Ramsden, Young, Home, and others, as to changes in the curvature of the lens, and especially of the cornea, because, I think, the elements for exactness are wanting. So slight an error in the estimation of form will so materially modify the calculations as to render these worthless; and I do not believe it is possible by any mechanical contrivance to measure the variations in curvature which may take place in the living eye when adapting itself to objects at different distances. The pressure of a segment of brass, or of any other substance, however thin it may be made, and however delicately applied, will be quite sufficient, not only to prevent such changes as the uncontrolled eye would undergo, but by its pressure to produce some abnormal alteration. Nor does the measurement of changes in the shape of the cornea effected by means of a bath of water placed upon it appear to possess the advantage of greater accuracy.

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* Miscellaneous works by Dean Peacock, vol. i.; and Philosoph. Transactions for 1791.

4th. That the adjustment of the eye to different distances is effected by a change in the position of the crystalline lens has been maintained by both mathematicians and anatomists, nor is this to be wondered at. When we see how readily the removal of a lens from or towards the recipient surface, according to the distance of the object, effects the purpose of correcting the variations in parallax, it is not an unnatural conclusion to suppose a similar simple plan may be adopted in the eye; and also from the fact, which, though sometimes disputed, appears to be undeniable, as was stated by Porterfield and again carefully investigated by Dr. Young, that when the lens has been removed or displaced from the axis of vision, the eye no longer possesses the faculty of adjustment. The idea of the lens being moved would be strengthened by an examination of the exceedingly complex structures about the base of the iris, and surrounding the lens, accordingly by some of the older anatomists it was thought that the ciliary processes were muscular, and their action to be that of pulling forwards the crystalline lens when near objects are viewed, and thus increasing the focal length of the eye. This opinion of the lens being pulled forward by the ciliary processes was warmly espoused by Porterfield, who as decidedly opposed the idea subsequently contended for by Dr. Young, that there is or can be any change in the form of the surfaces of the lens.

Against this opinion some serious and weighty objections have been raised. 1st, it has been shown, that, on the supposition of the adjustment being effected by *simply* increasing the distance between the lens and the retina, it would require a far more considerable alteration in position than does or can occur. 2ndly, it has been shown, that the ciliary processes are not connected with the lens as Munro and others supposed, and further that these processes are not muscular—objections which appear conclusive against the theory.

5th. To the opinion that the adjustment of the eye is effected by an elongation of the whole axis of the organ independent of any other change, the statement of Dr. Porterfield and particularly the experiments of Dr. Young are a sufficient answer, for though the anatomical reasons advanced by Porterfield, who was certainly a much better mathematician than anatomist, are of but little or no value, his optical experiments were unexceptionable; and those of Young appear clearly to demonstrate, that, if the change be solely by an elongation of the axis of the eye, it must amount to from one-sixth to one-seventh of the diameter of the ball, and consequently that there could be no difficulty in ascertaining it by observation and measurement; and in the next place, though Porterfield was in error in his account of the anatomy of the eye in refuting the opinion of Keill, Boerhaave, and others, that there is no mechanism by which the axis of the eye can be elongated; it may readily be conceded there is not any by which it can be effected without other changes also being at the same time produced. That the axis of the eye is elongated is more than probable, but it obviously is not the only cause of adjustment.

The great difficulty which surrounds this problem is, in my opinion, mainly owing to such exclusive views having been taken of the change which occurs: each one attempting to show that it depends upon change in one structure or upon a single alteration in the eye. In the discussion it must be allowed that each advocate has been far more successful in showing the insufficiency of the view which he opposed, than satisfactory in establishing the correctness of his own; it being evident, that no one of these change, separately and alone, does produce the result contended for. In effecting the adjustment of the eye the change which takes place is probably a very varied and complex one, according as the object is more or less remote, or very near to the eye—possibly several, if not all, of the changes above singly referred to concur in producing the effect.

In middle life the eye may be regarded as in a quiescent unexcited state, and hence in its natural condition, when viewing objects at a distance of from one to two feet, more or less, according to the size of the object, and the particular formation of the individual eye. When for any length of time we strive to observe a very remote object the eye becomes tired, and we are sensible of an effort, but this strain upon the eye and consciousness of an effort, which, indeed, soon becomes painful, is far more perceptible when very near objects are examined, the effort being in proportion to the nearness of the object. For it is only within certain moderate limits that the power of adjustment is enjoyed.

1st. The first change then in adapting the organ to overcome the aberration of parallax is in the condition of the iris. When a near object is looked at the pupil contracts; in regarding a distant one it dilates. This is an involuntary action.

2nd. In very near vision the crystalline lens is probably slightly pulled or projected forwards; in distant it is allowed to recede towards the retina.

3rd. It is not impossible, though by no means proved, that the state of the lens alters, becoming more spherical or flatter according to the nearness or distance of the object looked at.

4th. The cornea becomes altered in its shape; the radius of its base being larger or smaller in distant or near vision; hence the cornea becomes more convex, and its refractive power increased, when near objects are seen, and flatter and less refractive when distant things are looked at.

5th. The axis of the eye from before to behind becomes sensibly elongated or shortened according to the distance of the object.

In order to understand how changes are produced, and also to appreciate the probability of such changes being effected or not, it will be necessary to refer, not alone to the structure of the human eye, but also to some of the variations which are found to occur in animals, which throws considerable light upon the subject. By referring to the various figures of the human eye and those of animals the student will more readily understand what is advanced.

1st. That the pupil contracts when near objects are regarded, and dilates *cæteris paribus* when distant things are looked at, has been so often mentioned, and is so easily observed, that it need not now be dwelt upon. The optical reasons for this as well as the other uses of the iris have also been pointed out.

The non-admission of the muscularity of the iris, any more than the opinion of the involuntary character of its motions, does not in the least militate against these uses. In fact, these might be regarded as among the most evident and beautiful provisions of nature to protect the important organization of the eye. The manner in which the nerves, from the lenticular ganglion, which supply the iris, the ciliary circle and processes, are connected with the sensitive and motor nerves of the appendages of the eye, and the quick and instantaneous, often to us unconscious, manner in which all these parts, possessing otherwise no organization or necessary motion in common, co-operate in moving and protecting the eye, shows a far more perfect mechanism than if these movements had needed the control and direction of volition in all cases; quick as this is, had it been necessary, doubtless, at times, when the attention is otherwise occupied, serious and irremediable mischief would result.

2nd. That the crystalline lens undergoes a change of position, being drawn forwards or not as the object is near to or distant from the eye, has been formerly maintained by some high authorities, which change they believed to be effected by the muscularity of the ciliary processes, their apices being, as they thought, attached to the margin of the lens, but as both of these opinions are erroneous, the idea of the lens being pulled forwards by them has not generally been adopted, the ground upon which it rested having been shown to be incorrect. But, though the idea of the mechanism by which the position of the lens may be altered, be obviously wrong, it by no means follows that the motion may not take place by some other means. The extremely complex structure of the ciliary processes has probably some important end beyond nutriment, and obstructing the light; the highly vascular character of them is such as to render it possible they are of an erectile nature; that when blood is forced into or retained in them, they become elongated, and as they are intimately connected with the anterior part of the vitreous humor, they cannot undergo an alteration in form, without this also undergoing a corresponding change. Now, though they are not actually attached to the edge of the lens itself, they are not very indirectly attached to it by means of the suspensory ligament, the position or tension of which cannot be changed without the lens being influenced by it, and even were it not so, as the lens is imbedded in the vitreous humor, it is obvious that if by any means this humor be pulled or pressed forwards, so also will the lens be projected, and consequently so much removed from the retina. The intimate structural, vascular, and nervous connection there is between the iris, the ciliary body and processes, and the ciliary muscle, all show their consentaneous action; and it may not improbably be, that the common place of attachment of these to the junction of the cornea and sclerotic is the fixed point towards which all act; and that when the pupil is contracted by the circular fibres of the iris, the ciliary muscle pulls forwards the vitreous humor, and the lens with it, the cornea being at the same moment rendered somewhat more convex. In distant vision the ciliary muscle would be relaxed, the circular fibres of the iris would not contract the pupil, and there being no strain upon the rim of the cornea, its surface would become less convex.

But independent of this internal motion forwards of the lens, it is probably pressed forwards in a general lengthening of the axis of the eye by external causes.

3rd. Lieuwenhock imagined that the form of the lens is changed by the muscularity of its containing capsule, while John Hunter, Dr. Young, and others, asserted that the lens itself is muscular: so evidently neither the lens nor its capsule are muscular, that these opinions have not found much favour, nor many supporters, but the names mentioned are of themselves sufficient guarantee that the idea is not an absurd or improbable one. It must be admitted that we have no proof whatever of the lens undergoing any change in shape or density, yet when the wonderful nature of its organization is considered, and that the arrangement of its fibres varies in different animals, but in those of the same species it is always uniform, it appears inconceivable that such a peculiar arrangement should not be for some other purpose than securing a graduated density. One thing is certain that when the lens is removed, as in the operation for cataract, the eye loses its power of adjustment to different distances, which, as we have seen, Porterfield regarded as a proof that adjustment takes place by a change in the position of the lens, Dr. Young of an alteration in the curvature of its surface. It is not necessary, in order to undergo some internal change, that the lens should be muscular. True, muscle may be the only active and voluntary motor power in the body, but other forces are also employed, as erectile and the yellow elastic tissue. That the capsule of the lens is highly elastic is beyond dispute, and equally so, that the suspensory ligament by which it is maintained *in situ* is also. It is quite possible that the lens and its capsule are in some measure opposing forces, which, in a quiescent state of the eye, exactly counterbalance each other, but which, by some unknown means, as varying external pressure, are capable of being altered, so that the fibres of the lens may distend the capsule, increasing its sphericity; or that the capsule may compress and flatten the lens; and that the complex arrangement and interlocking of the fibres of the lens are for the purpose of securing that uniformity throughout its body in this change, which is essential to its perfect refractive power. There is no proof of this, but it does not appear as altogether improbable.

4th. That the cornea undergoes some alteration in its shape, being more prominent at one time than another, is I think certain. For though it may readily be admitted that Dr. Young, by his experiments and calculations, has satisfactorily shown that the adjustment of the eye to the aberration of parallax is not, nor can by any possibility be effected by an alteration in the radius of the cornea alone, yet they do not disprove those experiments which have been made with the greatest care by other persons, as Ramsden and Home, and which decidedly show that some change in the form of the cornea does occur. This, an attentive examination of the relative position of the different structures within the orbit will decidedly tend to confirm. Without at all being convinced of the existence of the circular muscle at the margin of the cornea in birds alone, I would remark that it is impossible the axis of the eye can be elongated by external force without an increase in the convexity of the cornea.

5th. While we may unhesitatingly admit that no such great elongation of the eye takes place, that required being, as Dr. Young has shown, equal to the one-sixth or one-seventh of the diameter of the ball, as will *alone* produce the adjustment of the eye to very near vision, and, therefore, so far agree with him, as to say, that it is not the sole means by which the aberration of parallax is corrected, yet there can, I think, be no doubt that he goes too far considerably when he does not allow any elongation of the axis to take place.

The more carefully the eyes and their appendages in various animals are examined will be observed such arrangements as must irresistibly lead to the opinion, that an elongation of the axis takes place by the pressure of the muscles of the eye-ball. It must be remembered that the outer case of the eye, the sclerotic and cornea, admits of being compressed, yielding in the direction of the pressure, and, as the contents of the eye are nearly, if not absolutely, incompressible, if the containing coat yields to the compression in one direction it must be distended in another.

Confining our attention for the moment to the human eye, look at fig. 75, page 108, it will be observed that the four straight muscles proceed from behind over the transverse axis of the eye, to be attached near to the cornea; while the two oblique muscles proceed from before (at least their fixed points) also over the transverse diameter, behind which they are attached. This part of the sclerotic is its thinnest and weakest part. Now these two sets of muscles, when acting together, will oppose each other. While the four straight muscles would, if acting alone, retract the eye, the two oblique would pull it forward and project it; acting together, they will compress it from side to side, and thus elongate it from before to behind, as the transverse diameter of the eye is pressed upon, and the antero-posterior is not. The axis is thus elongated and the cornea is necessarily projected forward, the radius of its base shortened, and hence its refractive power increased; at the same time the crystalline lens may be carried slightly forward, and the distance between it and the retina increased. Changes which, occurring together, and all co-operating, are sufficient to account for the power which the eye has of correcting the aberration of parallax. If an object examined be of a moderate size, and not very near to the eye, no perceptible feeling is induced, but if the object be minute, and brought close to the eye, then a consciousness of the effort and strain to perceive it, are very evident, and if persisted in soon becomes painful. There is, if attention be given to the sensation, a consciousness of contraction in all the parts concerned; the brows are drawn down, the lids partially closed, and the eyes protruded; while if a very distant object be sought for, the brows are elevated, the lids widely opened, the pupil is dilated, all near oblique rays excluded as far as possible by the shading hand over the brow, and, as I believe, by the sunken eye and flattened cornea from the relaxed condition of the ocular muscles.

The objection to the truth of what is here advanced which has been most relied upon, is rather of an optical than anatomical nature. It is asserted that such an elongation in the axis of the eye cannot take place, as if it did it would of itself produce indistinctness of vision, inasmuch as it is necessary that the surface of the retina should be smooth, and each portion of it preserved at a due and regular distance from the lens, in order that it may at the focal point of the lens receive the image; a position which, it is asserted, cannot be maintained if the eye undergo elongation.

While fully admitting the optical necessity here stated, I am disposed from this argument to draw precisely the opposite conclusion, and looking at the anatomy of the eye think it forms one of the arguments against those who have brought it forward. In fact there are many indications in the structure of the eyes of different animals which tend very strongly to support the opinion of this change.

There is a general provision to maintain a spherical form of the back part of the eye, so that the retina may, under all circumstances, remain accurately expanded at a proper distance from the lens, the parts being so arranged that this is not liable to derangement in the alteration of the other parts. In the fish we have seen that the anterior part of the eye is flat, but the back part is a segment of a sphere; while in the bird, where the anterior part is tubular, the posterior still retains its spheroidal form. In some fish, as the sturgeon for instance, the sclerotic coat encases a cup of cartilage particularly thick at the back part. While in all animals the posterior part of the sclerotic is the thickest and strongest, in those creatures whose eyes are subjected to great and varying pressure, as the seal and especially the whale, Figs. 124 and 125, the posterior part of the sclerotic coat is enormously thick. On the other hand examine the eyes of those animals which certainly possess in the highest degree the power of adjusting the eye to vision at different distances, as the rapacious birds, and we find their eyes so formed, as in a corresponding degree to admit of an elongation of the axis. The cornea is thin, large, prominent, and yielding; the aqueous humor is abundant, the iris exceedingly active and sensitive, the ciliary muscle and processes largely developed; a marsupium is present regulating the position of the lens; the anterior part of the sclerotic coat is thin, and prolonged into a tubular form, Figs. 131, 133, it encloses a layer of imbricated plates, which are so arranged as to allow this part of the eye to yield to compression, and thus to become elongated. Indeed had any one tried to devise a more perfect plan for permitting this compression he could not more effectively have arranged his structures. Had there not been yielding to compression at this part why the many imbricated plates, instead of one circular ring as would be were strength the only requisite? and why were they placed at this part of the eye, except to allow the axis of the eye to be regularly elongated by the projecting forewards of the cornea, and thus by its greater convexity increasing its refractive power, at the same time limiting the change to the anterior portion of the eye, the posterior spherical form, where the retina is, being undisturbed? The distance to which these creatures can see appears to us to be marvellous, so distant that the rays must be absolutely parallel, while they also are enabled to see distinctly at so small a distance, that the rays must be excessively diverging. That they can collect rays accurately into a focus upon the retina when proceeding from the point of the beak is certain, otherwise they would not be able to direct it with the precision they do. A similar arrangement of imbricated sclerotic plates exists in the eyes of reptiles, which obtain their livelihood both on the land and in the water, and which consequently must be able to see distinctly in both air and water, the effect of which will be analogous to the power of accommodation to excessive variation in distance in birds.

This power of accommodation, upon which I have dwelt at some length, but only so as to give little more than a glance at much of what has been said upon it, and not more than the importance of the subject and its confessedly obscure character requires, I believe then, not to be the effect of a simple change in one structure alone of the eye, but rather to be of a complex character, and to be explained by attending to slighter alterations in the general form of the eye-ball in which the various changes I have indicated occur, rather than to be the result of a great alteration in one structure alone. Besides which it is probable the extent of the alteration in the focal length of the eye, for adjustment to objects at different distances, has been much exaggerated. Calculations founded on the known refractive powers of the human eye show that the principal focus is nine-tenths of an inch from the centre of the cornea, and that the focus of a pencil of rays diverging from a point five inches distant, which is as near as objects can be distinctly seen by most persons, should be an inch from it, so that a variation in the focal length of *only one-tenth of an inch* is sufficient to explain how the eye is adapted to seeing with distinctness both near and distant objects. This small variation in form may not only serve to show that it may easily be effected, but also to explain how very difficult it must be to recognise and measure the alteration effected in the structure, more especially if these changes are not in one structure or direction alone.

On the Seat of Vision.—Since M. Mariotte made the interesting discovery of the insensibility of the optic nerve as it appears within the eye, and showed that it is unable to receive an impression from an image thrown upon it, the opinion which he suggested that it is the choroid coat, and not the retina, which actually receives the image and causes the sensation of vision, has from time to time found some supporters, especially amongst those opticians who are more profound mathematicians than learned anatomists and physiologists. Indeed the opinion, though not formally adopted by Dr. Reid and Sir D. Brewster, does not appear to be altogether discountenanced by them.

The arguments most relied upon by those who imagine that the choroid, and not the retina, perceives the impression of objects, and excites the sensation of them in the sensorium, are, 1st, the insensibility of the optic nerve, 2ndly, the softness and transparency of the retina, 3rdly, the supposed absence of the retina in the *foramen opticum*—the axis of the eye, at which vision is the most acute, 4thly, a circumstance mentioned by Sir D. Brewster, and upon which he appears to rely much, that in the eyes of some animals as in the *Sepia loligo*, or cuttle-fish, the dark opaque choroid coat is placed before the retina, so that no rays of light can reach the nervous tissue.

This latter objection would deserve all the importance given to it by Sir D. Brewster, were it correct, as it would be impossible to consider the retina, at least in these creatures, as the seat of vision, when the rays of light could not reach it. Though F. Cuvier described such to be the structure of the eye in these cephalopods, it is incorrect, and therefore valueless as an argument, or rather gives weight to the opposite opinion, for as before shown in these creatures as well as in all others, when there is the least reason from their habits to suppose that they enjoy a perception of the form of objects, the retina is in reality placed within, or anterior to, the choroid coat, occupying the same relative position as it does in the eye of man. All those creatures whose retinæ are not directly exposed to the rays of light are very low in the scale of animals, and there is no reason whatever, from observing their habits, to consider they are able to do more than just distinguish light from darkness, without the power of perceiving the forms of objects.

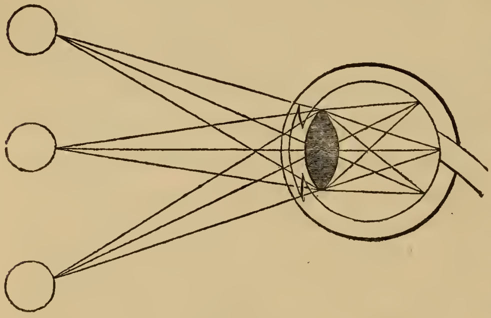

Fig. 147.

That the optic nerve is really insensible to light may be proved by a simple experiment, Fig. 147. Take three red wafers, and place them upon a wall two feet apart from each other, and upon a line level with the eye. Then stand opposite to the middle wafer, and closing one eye, fix the other eye upon the wafer nearest to the shut eye (if the left eye be closed, and the right open, upon the left hand wafer) gradually retiring from the wall it will be found, that when five times as far from it, as the wafers are from each other, that is ten feet distance, the two outside wafers will be seen, but the middle one will have disappeared. By calculation and measurement it is ascertained that the image of the middle wafer falls exactly upon the optic nerve. Analogous experiments have been devised by Mons. Picard and Dr. Porterfield, by which the image of an object is made to fall upon both optic nerves at the same time, when it in like manner totally disappears. If it be asked how it is that we are unconscious of this large insensible patch in our eyes—the answer is, that in consequence of the nerve entering the eye on the inside of the optic axis it is impossible for any object to have its image thrown on both optic nerves at the same time, so that what is unseen by one eye is always perceived by the other, which is sufficiently satisfactory when both eyes are used; but the explanation of no defect being perceived when objects are seen only with one eye is not altogether so. Porterfield's explanation is that the defect having been constantly supplied by the other eye is now supplied by imagination; but this it is difficult to conceive would still continue sufficiently vivid to counteract the deficiency in the case of persons blind of one eye for a great number of years. These experiments, however, are so decisive as not to admit of any doubt that the optic nerve itself is really insensible to light, and hence Mariotte's inference that the retina, which is made up of the fibres of the optic nerve, as they are spread out into their terminal extremities, is also insensible. Mariotte's experiment, however, really affords an uncontrovertible argument against the opinion which it has been supposed to support. The optic nerve in being insensible to light is only in the same position as all the other nerves of sensation are, it is only the terminal, minute, and delicate extremities of nerves, that are capable of exercising their functions, and not the large trunks themselves. No one will doubt that the fingers are the most delicate organs of touch, nor that they are so in consequence of the beautiful nervous expansions in their papillæ; yet if the large trunks which are in connexion with these nervous papillæ are touched, cut, or otherwise irritated, they give no sensation at all similar to that of touch. Nay more the sensation is not perceived at the point actually irritated, but it is referred to the distant extremities of the fingers, so if the trunk of the nerve be diseased, the sensation is perceived in the fingers, and the sense of touch altered and deranged; so also, when a limb has been amputated the pain, most frequently, is not felt in the stump which remains, and where certainly the cause of the feeling is, but is referred to the limb which has been cut off, and persons require some days before they can forget to say that they have pain or feeling in their toes or fingers. From this we learn that it is not the function of the nervous cords themselves to receive impressions, but to convey to the sensorium those impressions which the terminal expansions have received, while if the cord be cut no change is perceived, not because it is not impressed upon the nervous expansion, but because not being communicated by the cords to the sensorium no perception occurs. In the retina this is still more the case, for the true retinal elements, the rods and vesicles, are not present in the optic nerve, these are the true percipient structure, the nerve is merely the channel of communication between the true retina and the sensorium.

The softness and transparency of the retina, have been much relied upon by some, as serious objections to its supposed functions. That the retina will allow the rays of light to pass through it, is certain, and, that its softness is such as could not allow it to act as a vibrating body to well conduct vibrations, is equally true; but before admitting these objections it may be asked what proof is there that either opacity or vibratile quality is necessary to the constitution of a sensitive recipient surface? when it is shown how or why the image of an object thrown to the bottom of the eye should excite impressions upon the sensorium, then we may inquire what the character of the structure must be; before something be known upon the subject such speculations are worse than useless. A simple observation of a simple fact is more valuable than much hypothesis where the basis to found it upon is altogether wanting.—For anything known to the contrary it is quite as likely that a transparent structure may be essential to vision as that it is not. The most serious objection to the idea of the retina being the seat of vision is the fact of vision being the most acute and perfect, precisely in the axis of the eye, where the yellow spot exists, and which has generally been regarded as a distinct foramen, and consequently where there is an absence of the retina. Were this true it would be a fatal objection to the function of the retina; but I have before mentioned, when describing the structure of the retina, page 224, that this idea of a foramen I conceive to be founded upon the observation of a particular stage of a post-mortem change, to which there is nothing analogous during life, and that at this spot there really is no absence of the retina, but a full development of its true structures. In almost every animal no one pretends there is any such aperture. The arguments to be drawn from the anatomy and physiology of the eye are so strong, and the facts observed in diseases of the eye are so numerous, that no anatomist or surgeon will for a moment doubt that the retina is the sensitive surface which receives the image, the impression of which is conveyed along the optic nerve to the brain; and that the choroid coat has nothing immediately to do with the sensation. An explanation of Mr. Horn, who has written a pamphlet on the subject of the insensibility of the optic nerve to the direct impressions of objects is, from its curiousness perhaps worth mentioning, especially as one something analogous to it has since been offered by Mons. Lehot, as explaining how the eye overcomes the aberration of parallax, and takes cognizance of the three dimensions of objects. Mr. Horn asserted, that in all cases the inverted pictures which fall upon any part of the retina are instantly reflected in their various colours and shades upon the anterior portion of the concavity, from whence they are again reflected to raise images of the external objects in their natural order and position, near to the middle of the vitreous humor, and then fall upon the opposite base of the optic nerve, to be by it transmitted to the brain; thus, as he says, sensation is produced, and vision perfected. So that, according to him, the optic nerve is insensible to images in the inverted position to the objects, but sensible to those which are in the same position as the object, and that the purpose of the retina is to act as a reflector for the nerve; an opinion which it is unnecessary to spend time in refuting.

On the law of visible direction.—The actual place of an object and its apparent place are not always the same, it therefore becomes an interesting question to determine in what direction the object will be seen. This, it will be found, depends upon the part of the retina impressed by the rays—whatever be the course which these may take.

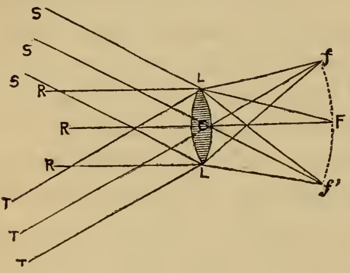

FIG. 148.

In Fig. 148 let F be the point of the retina on which the image of the point of a distant object is formed by means of the crystalline lens supposed to be at L C L. Now the rays, which form the image of the point at F fall upon the retina in all possible directions from L F to L F, and we know that the point is seen in the direction F C R. In the same manner the points *f f'* are seen somewhere in the direction *f'* S, *f* T. These lines F R, *f* S, *f* T, which may be called the lines of visible direction, may either be those which pass through the centre C of the lens L L, or, in case of the eye, through the centre of a lens equivalent to all the refractions employed in producing the image; or it may be the resultant of all the directions within the angles L F L, L *f* L, or it may be a line perpendicular to the retina at F *f' f*. In order to determine this point, let us look over the top of a card at the point of an object whose image is at F, till the edge of the card is just about to hide it, or, what is the same thing, let us obstruct all the rays that pass through the pupil excepting the uppermost, R L: we shall then find the point whose image is at F, is seen in the same direction as when it was seen by all the rays L F, C F, L F. If we look beneath the card in a similar manner, so as to see the object by the lowermost ray R L F, we shall see it in the same direction. Hence it is manifest that the line of visible direction does not depend upon the direction of the ray, but is always perpendicular to the retina. This important truth in the physiology of vision may be proved in another way. If we look at the sun over the top of a card, as before, so as to impress the eye with a permanent spectrum by means of the rays L F falling obliquely on the retina, this spectrum will be seen along the axis of vision F C. In like manner, if we press the eye-ball at any part where the retina is, we shall see the luminous impression which is produced, in a direction perpendicular to the point of pressure, and if we make the pressure with the head of a pin, so as to press either obliquely or perpendicularly, we shall find that the luminous spot has the same direction.

Now as the interior of the human eye-ball is, as nearly as possible, a perfect sphere, lines perpendicular to the surface of the retina must all pass through one single point, namely, the centre of its spherical surface, which point may be called the centre of visible direction. This doctrine, which was advanced by Kepler, has been adopted not only by Reed and Porterfield, but by many of the most distinguished opticians of the present day, and has been further illustrated and explained by Sir D. Brewster, from whom the foregoing figure and description are taken. It may therefore be considered as the true one, yet there are not wanting philosophers who doubt the correctness of it, nor others who deny it, Dr. Turner was indisposed to adopt it, and Dr. Griffen has instituted experiments which he thinks entirely refute it, though without converting many to his opinion—and in those animals whose eye-ball departs so much from a spherical form, an argument may be drawn against its applicability to them.

Erect vision from an inverted image.—As a necessary consequence of the eye being a dioptical instrument the image formed by it upon the retina is inverted with regard to the object itself. To explain why this inverted image should give the idea of an upright object as told by our sense of touch it is, as it is one of the most curious of the phenomena connected with vision, so it is one which has given rise to the most varied opinions and assertions. Some of these are learned and ingenious, others most absurd. Thus it has been alleged that though the image may after death be seen inverted, during life it is not so. That infants see all things upside down, and only by experience learn to correct the error of the eye by the sense of touch, a supposition which is every day contradicted by the movements of new-born animals, many of which perform such precise motions immediately after they are born as to show that their vision is precisely the same then as afterwards. The young partridge runs away with its shell upon the back, the duck waddles to the water, and the chicken picks up a grain of corn as soon as hatched, which had they to wait until experience had taught them the true position of things, they could not do.

Some persons have thought that as all objects, even portions of our bodies, are seen inverted, and their images are consequently in the same relative position with regard to each other as the objects themselves, as there is no confusion, which were some objects inverted and others erect there would be, so there is no consciousness of this, and that it is of itself a sufficient explanation of what is merely relative. This appears to be in substance Sir John Herschell's idea, and Dr. Lardner's explanation. The phenomenon has, says the latter, had undue weight given to it—for as inversion is a relative term, having reference to something not inverted, if all objects hold the same relative position none are inverted. As the world turns upon its axis once in twenty-four hours, it is certain that the position of all objects is inverted with respect to that which they held twelve hours before, and will hold twelve hours later, but as they are contemplated they are always erect. So in the retina, as all images hold the same position to each other, and they alone are the objects of vision, no one can be inverted with respect to another, consequently that position is called the erect position. Porterfield puts and thus answers the question—that the mind never sees any picture painted on the retina, and consequently never judges of the object from what it observes in this picture, for it has been proved that all our sensations are present with the mind and in the sensorium; and that in seeing an object, the mind by virtue of a connate immutable law, to which it has always been subjected, traces back its own sensation from the sensorium to the retina, and from thence outwards, along right lines drawn perpendicularly from every point of the retina, on which any impression is made by the rays forming the picture, towards the object itself; by which means the mind or visive faculty does always see every point of the object, not in the sensorium or retina, but without the eye in these perpendicular lines; but these perpendicular lines do nearly coincide with the axes of the several pencils of rays that flow to the eye from the several points of the object, and since the mind has also a power of judging rightly of the distance of objects, it from thence follows that every point of the object must appear, and be seen in the place where it is; and consequently the object itself must appear in its true erect position—notwithstanding its picture on the retina is inverted.

Dr. Alison explains erect vision by supposing that the filaments of nerves which are lowest in the retina proceed to the highest part of the brain with which they are connected, while the highest filaments in the retina proceed to the lowest part of the brain.

Sir D. Brewster thinks the law of visible direction removes every difficulty from the subject. That as the lines of visible direction necessarily cross each other at the centre of visible direction, those from the lower part of the image, going to the upper part of the object—and those from the upper part of the image, to the lower part of the object, an inverted image must as a necessary consequence produce an erect object, a conclusion which Brewster says may be illustrated in the following way:—

"If we hold up against the sun the erect figure of a man cut out of a piece of black paper, and look at it steadily for a little while; if we then shut both eyes, we shall see an erect spectrum of the man when the figure of the paper is erect, and an inverted spectrum of him, when the figure is held in an inverted position. In this case there are no rays proceeding from the object to the retina after the eye is shut, and therefore, the object is seen in the positions above-mentioned, in virtue of the lines of visible direction being in all cases perpendicular to the impressed part of the retina."

Des Cartes thought erect vision from an inverted image might be illustrated by the supposition of a blind man holding a stick in each hand and crossing them, so that with the stick held in the lower hand he touches the upper part of the object, and with that held in the upper hand the lower part of the object, being conscious that the upper part of the object corresponds with the stick held in the lower hand. I cannot but think these two illustrations are inappropriate. In that given by Sir D. Brewster there is proof that an impression will remain upon the retina for a certain time. The figure of the man being strongly impressed upon the retina by the vivid light remaining for a longer or shorter period after the light is excluded according to its intensity and continuance. If the figure be seen in the same position it was thrown upon the retina by the light proceeding from the object it can in no way illustrate how that image was produced, its perception being only a continuance of the impression previously produced by the light, and not dependent upon a process still going on; or, if it be so by a process still in action, and the position of the spectrum be reversed from that of the image during the admission of light, as Sir D. Brewster seems to imply; then it will prove something more, and would show that by an internal power the form of an image may be changed. To the illustration of Des Cartes, there is this most obvious objection, the blind man is conscious of the position of the two sticks, which he can cross or not at his will and vary the position as he may please. Now nothing of this kind occurs in vision, there is neither volition nor consciousness, so far as the formation of the image is concerned; hence as we are perfectly ignorant of the impression of an image at all upon the retina, it is impossible there can be any knowledge of the relative position of the parts of the image and the object to each other. The blind man knows the position of the object only because he previously knows the position in which he directs his hands. This knowledge in the formation of an image upon the retina is altogether wanting, hence the inapplicability of the illustration.

Neither does the explanation of Sir John Herschell nor Dr. Lardner offer to my mind any solution of the difficulty. It is a simple statement of fact and not an explanation of how the phenomenon occurs. We know perfectly well that if our sense of touch tells us two objects are in reverse positions as regards each other so does our sense of sight; and that if all objects are in the same relative position to each other and we to them, as is the case in the revolution of the earth on its axis, no different perception does or can occur. What we want to know is, how from an image painted on the retina in a relatively inverted position, objects shóuld to the eye appear in same position which our sense of touch assures us they are in, which the explanation does not tell. I am inclined to regard the perception by the mind of an object in a reverse position to that of the image of it upon the retina as a necessary law of the structure and function of the parts, as the perception of it by touch in a direct and upright position, appears to be a law of our perception by touch, but the cause or reason of this in the present state of our knowledge is altogether beyond our conception; that it may hereafter be ascertained, whether dependent upon the mode of connexion of the sentient filaments with the sensorium or not, is probable; I would however suggest for consideration whether it might not be better before attempting to explain why an inverted image should give rise to the idea of a reverse position of objects it should be explained why an image thrown upon the retina should in any way or manner give rise to the perception of an external object. When this is explained we may proceed to inquire why the position of the two should be reversed, until then the knowledge of the fact itself must suffice. It is a physiological and mental phenomenon, the solution of which must, I apprehend, depend upon a more precise acquaintance with the minute structure and functions of the optic nerve, retina, and sensorium, than we at present possess. The explanations of the opticians are of too physical a character to be altogether satisfactory to the physiologist.

On distinct vision.—It has been stated that the axis of the eye is the most sensitive part, the acuteness gradually declining from this point, so that the more distant any image is thrown from this spot, the less distinct will be the perception of it. Hence it is that only one part of an extended prospect is distinctly seen, the whole of it is perceived with sufficient distinctness to make us acquainted with its general features and to enjoy its beauties, but by a little attention we soon become conscious of the necessity for our directing the axis of the eye in succession to the different parts of it, if we would have a vivid and distinct perception of the varied objects it contains, so as clearly to remember them. It is this necessity for constantly varying the direction of the eyes that gives rise to much of the animation of the countenance. Various explanations have been given of this fact, but it probably is simply a law of the structure of the retina, as of other tissues, which is most developed at its posterior part, and as the elements of it gradually diminish as it proceeds forwards so does its acuteness and power of perception also lessen. Besides the particular spot, the distinctness with which the image is impressed upon the retina, the degree of illumination, the sharpness of outline, and length of duration of image are all of much importance.

Another most important element in distinct vision is the state of the mind when any object is placed before the eye. If the mind be pre-occupied with any matter of importance, either it does not take cognizance of the impressions of the senses, or, if perceived for the moment, they are immediately forgotten. So also if attention be engrossed by another of the senses, but little is seen by the eye; the gourmand who is intent upon the gratification of the palate sees little of the beauty of nature by which he may be surrounded, and still less will the musician, who is listening to some favourite strain, attend to the impression made upon the eye. An absent man may have all sorts of movements made before him without knowing anything about them, not because no image of them falls upon the retina, but because the sensorium is not attending to the impressions. When in deep thought the eyes may be wide open yet nothing be seen. Thus the sensation becomes more intense according as the particular object is at the time the principal object of mental contemplation: any compound mathematical figure produces a different impression according as the attention is directed exclusively to one or the other part of it. Thus in Fig. 149, according to the degree of attention which we give to the whole figure, to one or other of the three larger triangles, or to the six smaller, we may have a vivid impression of the whole, or only of one part of it; and of course the more complicated the figure, or the more numerous the objects in a landscape, so may the impression be varied.

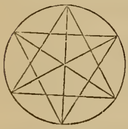

Fig. 149.

The duration of an impression upon the retina.—The impression which an object makes upon the retina does not instantly disappear, but will remain for an appreciable space of time, the length of which will materially depend upon the length of time the eye has been fixed upon the object, and also the intensity of the colour and light: when they are strong the impression may remain for the one-third of a second, Newton thought for a whole second. There are many simple and familiar illustrations of this fact. Thus a flash of lightning appears much longer than it really is—a falling star, as it is popularly called, often appears as a stream of vivid light. A burning stick whirled rapidly round appears to be a circle of fire. If the seven prismatic colours be properly arranged, in their due proportions in a circle, and this be turned round rapidly, a white surface is the result. Again, if a piece of cardboard or strong paper be folded into a strip about an inch wide, and the one half of the letters of a short sentence be printed or written in a bold hand upon each side of the paper, and this be then made to revolve rapidly by twisting strings attached to each end, the sentence becomes perfectly legible as though the letters were each complete in itself. If a small bird be painted upon one side and a cage upon the other, the bird will appear to be within the cage. Disks may be constructed having odd joints or portions of the limbs of animals or parts of a large building painted upon them, which when made to revolve rapidly and viewed through a small aperture assume the form of the whole object. The spokes of a wheel in rapid motion appear to be a continuous solid. This is the explanation of amusing toys which under various names, as thaumascope, phantascopes, or magic disks have been constructed, where the impression of one figure shall remain upon the retina until the next is produced, so that the impression is a continuous one. Such also is the effect of a rocket, and a catharine wheel; in the latter there is a circle of fire seen, but the fire actually is only in one spot at the edge of the circle at any given instant, but the wheel revolves before the impression has passed off, hence the spiral circle. So also unless our attention be specially drawn to it we are unconscious of the constant closing of the eye-lids, owing to the impression of objects remaining during the short time vision is interrupted; yet we know that several times within each minute the upper lid passes over the pupil, and excludes the rays of light.

This duration of an impression upon the retina after the object itself which excited it has disappeared may be further illustrated by the following simple experiment. Fig. 150. Take a blackened board two feet square, A B C D, with a hole not more than an inch in size near to some part of its margin, as at E, then take a circular disk also blackened, but pierced with eight holes of the

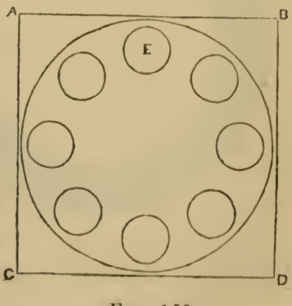

FIG. 150.

same size as that in the square board, and at such a distance from its margin as when attached by a central pin to the back of the board, the holes, when it revolves, shall exactly correspond with that in the board E, as shown. If the disk be now made to revolve slowly, as each hole comes behind that in the board, a white spot will be seen, and between them all will be black; but if the speed of the revolving disk be increased there will be seen a white spot constantly at the aperture in the board, showing that the inpression of one hole remains upon the retina until another hole succeeds. If now there be placed behind the disk a lighted candle it will be found that the revolution of the disk may be slower without the bright spot being lost, and if a camphine lamp or other strong illumination be used, still slower, showing that in proportion to the intensity of the illumination so is the duration of the impression. If different coloured glasses are placed over the lamp a similar variation in the duration will be found to occur. The impression remains longer with a red or yellow light than it does with blue.

Sensation not instantly excited.—If, however, impressions remain upon the retina for some appreciable period after the exciting cause has passed away, so on the other hand, a certain appreciable time is essential for the production of an impression upon the retina; for it is certain that an object may be placed before the eye, so that an image must be painted upon the retina; for as the velocity of light is so enormously great, not less than 200,000 miles per second, its passage from an object to the retina must be absolutely instantaneous; and there may not be the least consciousness of the presence of the object. Let a blackened screen having an aperture an inch square in some part of it be fixed at some distance from the eye, then upon a large disk, say two feet wide, describe a zone at its margin, not less than two inches wide, as

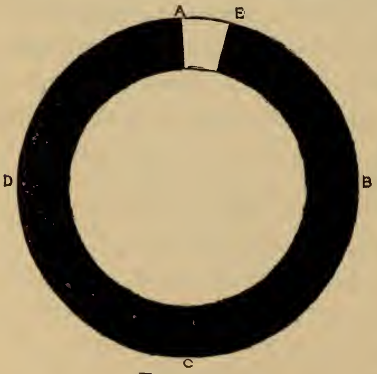

Fig. 151.

A B C D, Fig. 151, and blacken the whole of this zone, except one-twentieth part, as at A E. Then attach this zone by means of a central pin upon an upright standard so fixed behind the blackened screen, that the zone shall be exactly behind the aperture in it. If the disk be now made to revolve, at first slowly, the hole in the screen will appear white so long as the part A E of the zone which is not blackened is behind it, but in all other parts of the revolving zone it will of course appear black. This will be for the one-twentieth part of a revolution; if now the zone be made to revolve more rapidly the white spot will become less and less distinct, until as the velocity is increased the white spot will altogether disappear, and there be uniform blackness. Yet it is obvious that for a twentieth part of the revolution a white object is presented to the retina, so that the length of time requisite for the production of an image upon the retina is capable of being measured. This will be found to vary, first with the intensity of illumination, for in proportion to the degree of light so will a less space of time be necessary for its perception, and secondly according to its colour, some colours being more quickly perceived than others, for instance, a red spot is perceived in less time than a blue one. From this necessity for an object remaining a certain time in one place so that its image may be sufficiently impressed upon the retina to produce vision, it happens that a substance may pass before the eye and not be seen, while at other times, though it moves with as great velocity, it may be visible. Thus a cannon ball may pass transversely to the line of vision and not be seen, but if the eye be placed in the direction in which the ball moves, so that the angular motion of the ball round the eye as a centre be slow, notwithstanding its great velocity, it will be visible, because, however rapid its real motion through space, its angular motion with respect to the eye will be sufficiently slow to allow of the time necessary for the perception of it.

Exhaustion of retina.—But though a certain length of time is necessary for production of visual perception, and when excited the impression remains for a period after the object which excited it has passed away, these have their limits, for if much prolonged the retina soon becomes exhausted, and then altogether insensible to the same impression, which was so vividly perceived just before. Thus, if the eye be steadily fixed upon one object it will be found that the eye shortly becomes tired, and disposed to wander from it, which disposition requires considerable effort of the will to counteract, but if the eye be resolutely kept fixed the object itself will disappear. First the duller parts, then the lighter; if it be a picture the painting disappears, and then the frame, but the least motion of the eye will instantly restore the whole object, as the momentary impression of another object appears to be sufficient to allow the sensibility of the exhausted part of the retina to be restored.

Complementary colours and ocular spectra.—Very closely connected with the subject of the exhaustibility of the retina to the same impression is the very interesting one of accidental or complementary colours. If any small bright coloured body be attentively observed for some time, and the eye be then turned upon a sheet of white paper or a white wall, it will not appear to be uniformly white, but a spot of the same size and shape as the coloured body from which the eye has just been turned will be perceived. This spot, although of the size and shape of the body, is of a colour the very opposite: if a red wafer be the object, a round spot of a bluish green colour is seen upon the white paper: if the wafer be of the latter colour, then the spot is red: if the wafer be black, the spot will be white; if white, then the spot will be black. The colour of the wafer being given it is quite easy to predict the exact colour which the spot upon the white surface will present.

It must be borne in mind that white light is made up of variously coloured rays; white light being the effect of the combination of the whole rays, in exactly that proportion in which they exist in sunlight. Now if by any means any one of these coloured rays be subtracted, then those which remain produce a coloured light, which by the mixing of it with the subtracted colour will again produce white light.

The colour so observed was called by Buffon the accidental colour. It is now more commonly known as the *complementary colour*, because when mixed, as just said, with the prismatic colour it will produce white light, and the appearance of it depends upon the sensibility of the retina having been exhausted by the prismatic colour (red for instance), and, consequently, when the eye is turned from this, and white paper is regarded, that portion of the retina does not perceive the red rays in the white light, and hence the bluish green spot; so if a bright white spot be looked at the retina becomes insensible to all the rays, hence black is the complementary colour to white, and white is the complementary to black. When a black wafer is placed upon a white ground, that part of the retina where the image falls is protected by the black wafer, while the other portions of it are exhausted by the white light; so that when the eye is turned upon a sheet of white paper the white spot is seen, the other parts of the retina not being so sensitive. It is worthy of remark as showing the beautiful adjustment, and consentaneous action between the two eyes, that if one eye be shut and a bright object be regarded, an ocular spectrum may often be observed with the other eye. In some experiments, which Sir D. Brewster relates as having performed, in which he tied up the right eye, and viewed a brilliant image of the sun's disk formed upon a white ground by means of the concave speculum of a reflecting telescope with the left eye, when the right eye was unbound and turned upon a white ground, a coloured spectrum was observed with it as well as with the left eye, but this spectrum was always of the complementary colour of that seen with the left eye.

If the eye be steadily directed upon the rising or the setting sun when it appears red, and the eye-lids be closed, a green disk will be perceived.

The following is Brewster's list of the prismatic colours with their complementary or accidental:—

Prismatic.	*Complementary.*
Red . . .	Bluish green.
Orange . . .	Blue.
Yellow . . .	Indigo.
Green . . .	Violet reddish.
Blue . . .	Orange red.
Indigo . . .	Orange yellow.
Violet . . .	Yellow green.
Black . . .	White.
White . . .	Black.

In order to find the accidental colour of any colour in the spectrum, take half the length of the spectrum in a pair of compasses, and setting one foot in the colour whose accidental colour is required the other will fall upon the accidental colour. Hence the law of accidental colours, derived from observation, may be thus stated. The accidental colour in a prismatic spectrum is that colour which, in the same spectrum, is distant from the first colour half the length of the spectrum: or, if we arrange all the colours of any prismatic spectrum in a circle, in their due proportions, the accidental colour of any particular colour will be the colour exactly opposite that particular colour; from which the two colours have been called opposite colours.

If with Sir D. Brewster we suppose there are only three primary colours in the spectrum, and that the other are intermediate between these primary colours, resulting from an intermixture of the rays of the two primary colours, we may illustrate this by his diagram. In Fig. 152 the three primary colours are placed at the angles of a triangle, and the secondary, intermediate between them. By connecting each of these with a line drawn through the centre of a circle, it will be found that the prismatic and complementary colours are in all cases exactly opposite to each other, and connected by the central line. So also if we suppose the circle to contain every intermediate shade, those which when united yield a white or grey colour will always be found directly opposite to each other. Thus, for example, the intermediate tint between orange and yellow, is complementary to the middle tint between violet and blue, or indigo.

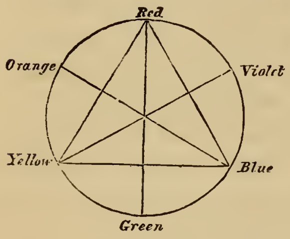

Fig. 152.

It is an exceedingly curious fact that the eyes of some persons are altogether insensible to certain colours, the sight being perfect in every other respect, and what is still more extraordinary this defect appears to be hereditary. The colours which cannot be perceived vary in different persons, but the red rays, or those colours into which the red rays enter, are, I think, those which are more commonly not perceived, or the shades of which are undistinguished from each other.

The late Dugald Stewart could not perceive any difference in the colour of scarlet, Siberian crab and the green leaves; the difference in shape he perceived as well as any person could do. I have known of at least three similar instances, all in men. Dr. Dalton could not tell the difference between pink and blue; and red was almost unperceived as a colour by him. His unconsciousness, when first arrayed in the gay-coloured gown appertaining to the dress of D.LL. of the University of Oxford as he appeared in the Radclyffe Room at the evening meeting of the British Association, of their inappropriateness to the sober and decorous hue of his Quaker garb is said to have been most ludicrous.

I know of an instance of a gentleman who cannot tell browns from greens, one or two of his uncles had, and some of his nephews have the same defect, while none of the females of his family, so far as I can learn, are so circumstanced. Similar instances are on record.*

In some the defect for colour is so great that only black and white can be distinguished, all dark colours being called black, and all light colours being called white. This great defect is rare, but I believe in a lesser degree the inability to distinguish between shades is very common indeed, quite as much so as the inability of the ear in other persons to appreciate certain sounds.

More than one explanation of this curious defect has been proposed. Dr. Dalton supposed that his vitreous humor was blue, and therefore absorbed the red and other less refrangible rays,—an explanation which is in the highest degree improbable, and quite unsatisfactory. Sir John Herschell attributes it to a defect in the sensorium, which renders it incapable of appreciating those differences between the rays upon which their colour depends. I should, however, be much more inclined to think the defect is seated in the refracting apparatus of the eye itself; that possibly the fibres of the crystalline lens vary somewhat in their structure or arrangement by which they affect in a less perfect manner than ordinary the differently refrangible rays; or it may be that, supposing the retina is called into action in accordance with the length of vibrations of the different coloured rays, it is in these individuals insensible to the impressions of particular vibrations, so as not to be excited by them, or being excited only conveys the impression of the certain coloured rays.

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* At the present time I have a patient, a well-educated and intelligent gentleman, who was brought up under the most favourable auspices as an artist, and pursued the profession for many years. His painting was never satisfactory, and he has recently been compelled to abandon it in consequence of this defect in the appreciation of colour, which, as in others, is principally in the various shades of red and brown:—none of his brothers or sisters, and there are several, have any defect, but two uncles had. The defect is not often noticed in children, perhaps from being overlooked or not appreciated. I have, however, recently had brought under my notice by Mr. F. R. Pickersgill, R.A., the historical painter, the case of a boy only six or seven years old, in whom the defect is very apparent. At my request he has been good enough to ascertain if the other children of the family are similarly circumstanced; but so far as can be made out, this is not the case, nor in any of the former generations.

That Dalton's notion of his vitreous humors being blue was erroneous was proved by these being found after his death as colourless as in other persons.

The want of an eye for colour is in some measure akin to this. Persons of good education and otherwise refined feeling will not unfrequently be seen to dress themselves in the most inharmonious colours. I know one gentleman (a physician) who sometimes dresses himself in such incompatible colours, his cravat, waistcoat, and coat being all disharmonic, as to look quite strange; so that his wife thinks it necessary to induce him to change one or more of these three articles of dress before going out, he all the time thinking his toilet quite in character and appropriate. Some painters who are excellent draughtsmen, and who can compose and arrange a picture most admirably, never produce a pleasing or effective work from their not being able to harmonize and balance the colours in the pictures. They know every shade, but appear not to feel the harmony or incongruity of colours. This must be a mental or sensorial defect, analogous to the want of appreciation of the cords or discords in music in a person whose hearing is otherwise good.

Size of Image on the Retina.—In order that objects be seen it is essential that the image of them upon the retina have a certain magnitude as well as distinctness. If a white circular disk one foot diameter be placed at a distance of 57½ feet from the eye the axes of the pencils of rays proceeding from it to the eye will be included within a cone whose base is the disk, and whose vertex is in the centre of the eye. These axes, after intersecting at the centre of the eye, will form another cone, whose base will be the image of the disk upon the retina. The common angle of the two cones will in this case be 1°.

Suppose A B, Fig. 153, be the diameter of the disk, C the

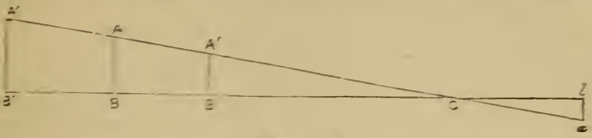

FIG. 153.

centre of the eye, and *a b* the diameter of the image on the retina. From the perfect similarity of the triangles A C B and *a* C *b*, it is certain that the diameter of the image *a b* will have to the diameter of the object A B the same proportion as the distance *a* C of the retina from the centre C has to the distance A C of the object from the same centre. Therefore, in this case, as one-half of the diameter of the eye is but half an inch, and the distance of the disk A C is supposed to be 57½ feet, the magnitude of the diameter *a b* of the image on the retina will be found by the following proportion :—

$$a\,b : \mathrm{A\,B} :: \tfrac{1}{2} : 57\tfrac{1}{2} \times 12 = 690$$

we therefore have $a\,b = \frac{\frac{1}{2} \times \mathrm{A\,B}}{690} = \frac{6}{690} = \frac{1}{115}$.

The diameter, therefore, of the image upon the retina would be the $\frac{1}{115}$th part of an inch.

If the disk were removed to twice the distance, that is 115 feet, the angle of the cone C would be reduced to half a degree, and the diameter of the image on the retina would be reduced to half its former size, or the $\frac{1}{230}$th of an inch. If, on the other hand, the disk be placed at half its original distance from the eye, the angle C will be increased to 2°, and the size of the image upon the retina be double its first magnitude—$\frac{2}{115}$ths.

Visual Magnitude.—The angle which is thus formed is called the visual angle or the apparent magnitude of an object, and when it is said that a certain object subtends the eye at a certain angle, it is meant that the lines drawn from the extremities of such object to the centre of the eye form such angle. The apparent magnitude of an object, however, must not be confounded with its apparent superficial magnitude, as the term is invariably applied to its linear magnitude. The apparent superficial magnitude varies in proportion to the square of the apparent magnitude. Thus, for example, when the disk A B is removed to double the original distance from the eye, the apparent magnitude, at the angle C, is diminished one-half, and consequently the diameter *a b* of the picture on the retina is also diminished by one-half, and since the diameter is diminished in the ratio of 2 to 1, the superficial magnitude of the image, or its area, will be diminished in the proportion of 4 to 1. So that when an object is moved to or from the eye, its apparent magnitude varies inversely as the distance; that is, its apparent magnitude is increased in the same proportion as its distance is diminished, and *vice versâ.*

From this it follows that all objects which are seen under the same visual angle will have the same apparent magnitude. Thus, supposing in Fig. 153 there are three objects A′ B′, A B, and A″ B″ placed before the eye at varying distances, but of such sizes that the highest and lowest point of all these should lie upon the lines A′ C and B′ C, it is obvious that the angles which they all form would be of the same size, and consequently that the size of the image of all three upon the retina would be equal, and hence the apparent size of the three objects would be the same, though the actual size be very different according to the actual distance of each from the eye. So that the visual angle is the measure of the apparent, but not of the actual magnitude. This fact is admirably illustrated by the sun and moon. The full moon appears to be of equal size with the sun, yet it is well known that the diameter of the sun is really about four hundred times that of the moon, but as the distance of the sun from the earth is about four hundred times that of the moon, the proportion of the distance and the diameter of these two objects is the same; so that the apparent or visual magnitude of them is equal, whereas the sun is really above one hundred and sixty-two thousand times the bulk of the moon.

The smallest magnitude which can be distinctly seen.—In Fig. 153 the disk has been supposed to be one foot diameter, and to be placed 57½ feet from the eye, in which position the visual angle will be one degree. If it be removed sixty times as far off, or to 3,450 times its own diameter, the angle which it subtends at C will be sixty times less, or one minute, and if to 6,900 times its diameter the visual angle will be only thirty seconds, under which, if it be well illuminated by the light of the sun, it will just be visible. This depends, however, upon the colour of the disk as well as its illumination, for Plateau says, that such a disk, if white, with the sun's rays falling directly upon it, will be perceived under an angle of twelve seconds, which is equal to a distance of 17,250 times its diameter. If the disk were red it would be seen under an angle of twenty-three seconds, and if blue, of twenty-six seconds. If the day were cloudy the angles must be half as large again as in the direct light of the sun, or it would not be seen.* This statement also shows how minute a speck upon the retina is sufficient to excite sensation, but the subject is so interesting and important that it deserves a little further illustration. The whole disk of the moon subtends a visual angle of half a degree, so that the diameter of its image upon the retina will be the $\frac{1}{230}$th of an inch, and the entire superficial magnitude of the picture, from which the distinct perception of the moon is derived, is less than the $\frac{1}{52,900}$th part of an inch square, and as we can distinctly perceive the lights and shadows formed by its mountains and valleys, which in linear dimensions do not exceed one-tenth of the apparent diameter of the moon, the space they occupy upon the retina does not amount to more than the $\frac{1}{5,259,000}$th part of an inch square. The features of a man 70 inches high, at forty feet distance, are distinctly seen. The size of the image his whole body produces upon the retina would, according to Lardner, from whom some of these illustrations are taken, be about the $\frac{1}{14}$th of an inch, while that of the face, in which all the features are seen, is not more than the $\frac{1}{170}$th part of an inch ; and though the eye can be distinctly seen, yet as its diameter is not more than the one-twelfth of the face, the spot upon the retina which its image occupies is not more than the $\frac{1}{4,000,000}$th of an inch square.

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* This statement of Plateau is so commonly regarded as correct, that it may appear presumptuous to offer any objections to it; but I doubt if it be not made too generally, as true under all circumstances. That a white body, with the sun's rays falling directly upon it, within a certain distance, and in certain degrees of light, is more distinctly perceived than any coloured body, is undeniable; but it appears to me not to be so invariably. Since the above was written, I have made some observations which have led me to this conclusion. On the high moorlands of Yorkshire, midway between Bolton and Patley Bridges, in a conspicuous spot, is erected a stone building as a shooting-box, called Rogan Hall: eleven yards directly behind it is another building. Both are quadrangular structures, which, though if not precisely the same size in all their dimensions, are so nearly so as to be practically the same, each presenting a front of about twenty-one feet diameter. The first building had just been whitewashed all over, roof as well as walls, in anticipation of the approaching 12th of August. The second building is of the usual gray hue of sandstone, roughly dressed, after many years' exposure. Within a distance of a mile and a-half or three-quarters, that is from 380 to 450 times the diameter, with the sun shining very highly upon them, the white building was the most conspicuous, particularly the nearer to the buildings they were observed; but beyond this distance at two miles and upwards the grey unwashed structure stood solidly out as a black mass, while the white surface of the first, by its own whiteness, appeared so nearly to harmonize with the air, so full of light, as to melt into it and become so indistinct that its outline was hardly visible, and if not indicated by the neighbouring black mass would have been hardly made out, but when the sun was obscured by a dense cloud, the conspicuousness of the two was reversed, the white became more distinct, and the grey more indistinct. The same variations I observed towards evening, when the light was faint. The explanation I suppose to be, that when the light is subdued, the greater reflection of it from the pure white renders it plainly visible, while not sufficient is thrown back by the grey stone for it to be seen, but that when the light is very intense, the reflection from the white is so great that the little which is absorbed is not very palpable, and thus the outline is indistinct, while with the grey the

Degree of Illumination.—For distinct vision the degree of light must neither be too great nor too small, for though the eye possesses within certain limits a beautiful power of accommodating itself to varying degrees of illumination, this has its limits. Thus the unclouded sun is so bright that no distinct sense of the appearance of his disk is conveyed by looking at him ; there is only dazzling, which soon becomes intensely painful and unsupportable ; on the other hand, there are numberless stars whose light is so feeble that to the naked eye they are invisible, but if their light be collected in a greater quantity by the aid of a telescope they are distinctly seen. It is for this reason that when a person goes from a dark room into the sunlight he sees nothing distinctly, until the pupil has had time to contract and thus diminish the quantity of light which overpowers the retina, and on the other hand, on going from a brilliantly illuminated

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absorption is so great as to render the mass dark or black ;—but that within a limited distance the brilliant white surface, like a polished mirror, throws back so much as to become dazzling. Whatever the explanation, however, may be, the fact is as I have stated. It must be for a similar reason that upon railways the stationary danger signals and tail lamps are not white, but red, as being more distinctly seen.

place into a dark one, he equally, until the pupil dilates to let in more of the feeble light, perceives nothing distinctly.

The distinctness with which an object is seen is also relative, and depends upon the quantity of light which other objects transmit to the eye at the same time. Thus the same object may transmit the same quantity of light to the retina, and nevertheless at one time be brilliantly seen, at another be scarcely, if at all, visible. The moon is a glorious object on a calm cloudless night; in the daytime she palls her ineffectual light: so with the stars, at night they are magnificently bright, during the day they are unseen. Yet they shine as brightly and send as much light to the earth during the day as during the night, but their feebler flame is overpowered by the intensity of the sun's rays. The retina being impressed with his strong light does not perceive the weaker of the moon and the stars, though receiving as much from them during the day as at night. The condition of the retina and the state of the mind also exercise a material influence. Thus if the retina has been subjected for some time to a strong light or intense colour, a feeble light or a pale colour, which under other circumstances would be perceived, is unseen. On the other hand, light so weak as to be insufficient for distinct vision to the dweller in daylight, is painfully strong to the prisoner just liberated from the dark dungeon. So with the mind, if excited to attention a feeble impression will be recognised which in a dull or listless condition will pass unheeded. The same thing occurs with all the other senses. When the ear is impressed with a loud sound it does not perceive a feeble one, and so with taste and smell. The well-told tale of the hearing of the bagpipes by one of the besieged women of Lucknow, if not true, deserves to be so, for its foundation is in nature.

The apparent brightness of an object is the same at all distances.—This without consideration we should hardly be inclined to think correct, as the light from an object decreases as the square of its distance increases, and therefore we might think the apparent brightness of its image would do so, and this it would in reality do, did the image of the object upon the retina continue to be of the same size at all distances, as then the light thrown upon it must be in proportion to that entering the eye from the object. But it must be borne in mind that the size of the image upon the retina (Fig. 153) decreases in the same proportion as the square of the distance of the object increases, it therefore follows, that as the image loses in size, so, in the same proportion, are the rays collected into a smaller space, and thus the degree of illumination is in the same proportion in the smaller image as it is in the larger one.

Dr. Lardner observes that if the sun were removed to ten times its present distance from the earth, its visual angle would be ten times less than it is at present, its apparent superficial magnitude would be an hundred times less than it is at present, but the splendour of its disk would be the same as now, and if it were brought as near to the earth as the moon, its apparent diameter would be increased four hundred times, and its area 160,000 times, but the apparent brightness of its surface would not be in any degree increased. So that supposing the planet Saturn to be inhabited, the appearance of the sun to its denizens would be not less bright but smaller, as though we saw him through an aperture in an opaque plate, which only showed one-tenth of his disk.

Light, if sufficiently intense, will continue to affect the retina when the object from which it emanates is removed to such a distance that the object itself has no visual angle, and hence the eye is affected by the light alone. Such is the case with a vast number of the stars, which even under the most perfect telescopes, merely appear as brilliant points.

Apparent Motion.—In considering this question it must be remembered that we estimate not by the real, but by the apparent motion of objects, that is, not by the velocity with which the object actually moves through space, but by the angle which the line drawn from the eye to the object describes per second. Now this angle is affected by two conditions, which it is important to attend to: 1st, the direction of the motion of the object compared with the line of vision; and 2nd, by the velocity of the motion compared with the distance of the object. If the object were to move exactly in the direction of the line of vision, it would appear to the eye to be absolutely stationary, since the line drawn to it would have no angular motion; and if it were to move in a direction forming an oblique angle to the line of vision, its apparent motion might be indefinitely slow, however great its real velocity might be.

"For example, let it be supposed that the eye being at E, Fig. 154, an object O moves in the direction O O′, so as to move from O to O′ in one second. Taking E as a centre, and E O as a radius, let a circular arc O O″ be described. The apparent motion of the object will then be the same as if, instead of moving from O to O′ in one second, it moved from O to O″ in one second.

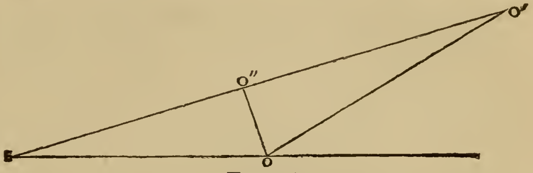

Fig. 154.

The more nearly, therefore, at right angles to the line of vision the direction of the motion is, the greater will be the apparent motion produced by any real motion of an object.

How apparent motion is affected by distance.—A motion which is visible at one distance may be invisible at another, inasmuch as the angular velocity will be increased as the distance is diminished.

Thus if an object at a distance of 57½ feet from the eye move at the rate of a foot per second, it will appear to move at the rate of one degree per second, inasmuch as a line one foot long at 57½ feet distance subtends an angle of one degree. Now if the eye be removed from such an object to a distance of 115 feet, the apparent motion will be half a degree or thirty minutes per second, and if it be removed to thirty times that distance, the apparent motion will be thirty times slower. Or if, on the other hand, the eye be brought nearer to the object, the apparent motion will be accelerated in exactly the same proportion as the distance of the eye is diminished.

A cannon-ball moving at 1000 miles an hour transversely to the line of vision, and at a distance of 50 yards from the eye, will be invisible, since it will not remain a sufficient time in any one position to produce perception. The moon, however, moving with more than double the velocity of the cannon-ball, being at a distance of 240,000 miles, has an apparent motion so slow as to be imperceptible.

What motions are imperceptible.—The angular motion of the line of vision may be so diminished as to become imperceptible; and the body thus moved will in this case appear stationary. It is found by experience that unless a body moves in such a manner that the line of vision shall describe at least one degree in each minute of time, its motion will not be perceptible.

Thus it is that we are not conscious of the diurnal motion of the firmament. If we look at the moon and stars on a clear night, they appear to the eye to be quiescent; but if we observe them after a lapse of some hours, we find that their positions are changed; those which were near the horizon being nearer the meridian, and those which were in the meridian having descended towards the horizon. Since we are conscious that this change did not take place suddenly, we infer that the entire firmament must have been in continual motion round us, but that this motion is so slow as to be imperceptible.

Since the heavens appear to make a complete revolution in twenty-four hours, each object on the firmament must move at the rate of 15° an hour, or at the rate of one quarter of a degree a minute. But since no motion is perceptible to the eye which has a less apparent velocity than 1° per minute, this motion of the firmament is unperceived. If, however, the earth revolved on its axis in six hours instead of twenty-four hours, then the sun, moon, stars, and other celestial objects would have a motion at the rate of 60° an hour, or 1° per minute. The sun would appear to move over a space equal to twice its own diameter each minute, and this motion would be distinctly perceived.

The fact that the motion of the hands of a clock or watch is not perceived is explained in the same manner."*

When objects are regarded the eye is moved in different directions, yet no idea of motion in the object is caused.—It has therefore been inquired why the object should not appear to be in motion instead of stationary. The explanation is, that though the eye-ball moves, yet, as the optical centre of the eye is the centre of the eye-ball, the various points from the visible object remain unchanged, however much the eye-ball may be moved; and as the corresponding point from the optical centre to the image must also remain unchanged, it follows that the image of the object remains fixed, while the retina moves under it as the ball revolves upon its centre.

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* Lardner's Handbook of Natural Philosophy: Optics.

Thus if we direct the axis of the eye to the centre O, Fig. 155, of any object, such as A B, the image of the point O will be formed at R on the retina, where the optical axis D C meets it. The axis of the pencil of rays which proceed from the point O will pass through the centre of the cornea D, through the axis of the crystalline, and through the centre C of the eye-ball, and the image of O will be formed at R.

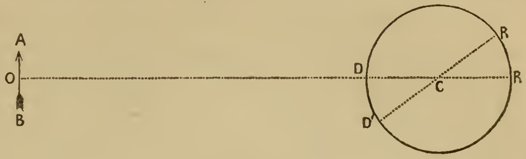

Fig. 155.

Now, if we suppose the eye to be turned a little to the left, so that the optical axis shall be inclined to the line O C at the angle D′ C O, the image of the point O will still hold the same absolute position R as before; but the point of the retina on which it was previously formed will be removed to R′. The direction of the point O will be the same as before; but the point of the retina on which its image will be formed, will be, not at the extremity of the optic axis, but at a distance R R′ from it, which distance subtends at the centre C of the eye, an angle equal to that through which the optic axis has been turned.

It is evident, therefore, that although the eye in this case be moved round its centre, the point O is still seen in the same direction as before.

But if the optical centre of the eye were different from the centre of the eye-ball, the direction in which the point O would be seen would be changed by a change of position of the eye.

To render this more clear let C, Fig. 156, be the centre of the eyeball, and C′ the optical centre of the eye. Let the optical axis C D as before, be first presented to the point O of the object. The image of this point will as before be formed at r, the point where the optical axis D C meets the retina. Let us now suppose

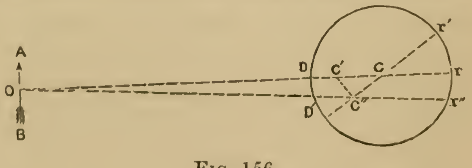

Fig. 156.

the axis of the eye to be turned aside through the angle D C D′, the optical centre will then be removed from C′ to C″, and the image of O will now be formed at the point r'', where the line O C″ meets the retina. The direction, therefore, in which O will now be seen will be that of the line C″ O, whereas the direction in which it was before seen was that of the line C O. The point of the retina at which the image r was originally formed is removed to r', while the image is removed to r''. Thus there is a displacement not only of the retina behind the image, but also an absolute displacement of the image, and an absolute change in the apparent direction of the object. Since no such change in the apparent direction is consequent to the movement of the eye in its socket, it follows that the optical centre C′ of the eye must coincide with its geometric centre C.

Single vision with two eyes.—Perhaps no one subject connected with vision has excited so much discussion or given rise to so many speculations amongst metaphysicians and opticians, anatomists, and physiologists, as this, nor is it to be wondered at; for no one can reflect upon the fact of a picture of an object being painted within each eye, and yet the perception of one object only be excited in the mind, without some wonder. If either eye be closed the object is distinctly seen, both eyes being opened still only one object is recognised, that is in a state of health and under ordinary circumstances, for in certain pathological conditions, and also at will within certain limits, objects may be seen double. So difficult is the solution of the question that many explanations have been offered, some of which are obviously incorrect, and some are highly ingenious, but no one is so satisfactory as to have obtained universal acceptance.

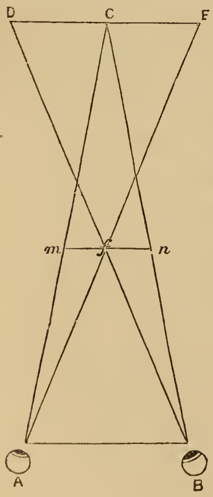

Fig. 157.

1st. Porterfield, with great learning and ingenuity, considered this question, and arrived at the opinion that single vision is a necessary consequence of the perpendicular direction of the visible lines, which all pass through the centre of the eye; that as an object is seen in the same place by both eyes it must appear single, because we can have no idea of the penetration of matter, or, which is the same thing, it is impossible for us to conceive two visible objects occupying the same place at the same time.*

Fig. 157 will illustrate that so long as the axes of the eyes are directed to an object it will appear single, but that when they are directed to a point either more remote or nearer than it is, it will immediately be seen double. Let C be a candle placed at any distance before the eyes, say twelve feet, the axes of the eyes A C, B C, being directed to it, the candle is seen single. If any body, as a stick, be placed between the candle and the eyes, as at *f*, so long as the candle is looked at the stick will appear double, but if the stick be looked at then the candle will appear double, the stick being seen single, and in proportion as the candle and stick are near to each other, or are widely apart, so will the double images be near to each other or widely separated. The double images in these two cases belong to the opposite eyes. If the axes of the eyes be directed to C, then the image of the stick in the direction *f* E will belong to the left eye A, and that in the direction *f* D to the right eye B. The double images always appear to be situated on the opposite side to the eye by which they are seen, when the eyes are adjusted to an object more remote than the one seen double. Thus the right-hand image disappears when the left eye is closed, and the left-hand image when the right eye is closed. On the other hand if the eye be directed to the stick at *f*, the candle at C is seen double: C then appears on the outside of the axis A *f* E of the eye A, and also on the outside of the axis B *f* D of the eye B, but in this case the double images will lie upon the same side to which they belong. The image of C which belongs to the left eye A is seen on the same side of the stick *f* as the eye A or towards D, and that image of C which belongs to the right eye B is seen on the right-hand side of *f* as towards E; so that when the left eye is closed the left-hand image disappears, and the right-hand image when the right eye is closed.

This explanation was adopted by Dr. Smith and many other learned men, and by no one has it been espoused more warmly than by Sir D. Brewster, who has pursued the subject with his usual ingenuity and skill, in devising experiments for its support. He not only does not entertain any doubt of the sufficiency of the explanation, but goes so far as to declare, that single vision with two eyes, or with any number of eyes, if we had them, is a necessary consequence of the law of visible direction. By the recti muscles the axis of each eye can be directed to any point of space at a greater distance than four or six inches. If, for example, we look at any small object, as a pin held in a strong light, we know that an image of it is formed in each eye, but as the line of visible direction from any point in the one image meets the line of visible direction from the same point in the other image, each point will be seen as one point, and, consequently, the pin seen by one eye will coincide with or cover the pin seen by the other. If the axes of both eyes are directed to a point beyond or nearer than the pin, it will appear double, because the lines of visible direction from the same point in each image do not meet at the pin. As the interior of the eye-ball is nearly spherical, lines perpendicular to the surface of the retina must all pass through one single point, that is the centre of its spherical surface. This point may be called the centre of visible direction, because every point of a visible object will be seen in the direction of a line drawn from the centre to the visible point.

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* Porterfield on the Eye, vol. ii. 308.

2nd. It was the opinion of Aquilonius that all objects seen at the same glance with both eyes appear to be in the plane of the horopter. This hypothesis has been adopted by several able men, and, with some modification, was that maintained by Dr. Wells in his "New theory of visible direction."

The horopter, Aquilonius defined to be a line drawn through the point of convergence of the axes of the eyes, and parallel to the line joining the centres of the two eyes. The plane of the horopter to be a plane passing through this plane at right angles to that of the optic axes.

All objects which are in this plane must appear single, because the lines of direction in which any point of an object is seen coincide only in this plane, and nowhere else, and as these lines can meet each other only in one point, it follows from the hypothesis, that all objects not in the plane of the horopter must appear double, because their lines of direction intersect each either before or after they pass through it, as Porterfield maintains.

But Müller has observed that the horopter can neither be a straight line nor a plane, but must have a circular or spheroidal form, and says it is always a circle of which the cord is formed by the distance between the eyes, or more correctly between the point of decussation of the rays of light in the eye; and of which the size is determined by three points, — namely the two eyes, and the point towards which their axes converge. If *a b*, Fig. 158, be the distance of the eyes from each other, the circle *f* is the horopter for the object *e;* the circle *g*, for the object *d;* and the circle *h* for the object *i.*

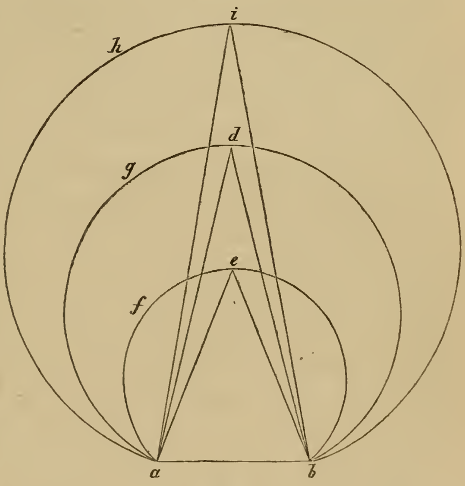

Fig. 158.

Professor Wheatstone has however adduced such experiments as he thinks clearly prove that when the optic axes converge to any point which may be placed before or beyond the plane of the horopter, objects are under certain circumstances equally seen single as those in that plane, and, therefore, he thinks he has demonstrated this theory of single vision to be untrue.*

3rd. A third theory maintains that although both eyes are open we in reality see with only one, the one eye being at rest while attention is given to the other which is on duty, but this opinion though supported by men of name may easily be shown to be untrue, and that we use both eyes in ordinary vision is certain. When the axes of the eyes do not converge, as from pressure upon one eye, squinting, intentionally directing the axes of the eyes to a point before or beyond. an object seen,

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* Philosophical Transactions for 1838, Part 2nd.

(Fig. 177,) as often occurs in fainting, intoxication, tumours in the orbit, disease of the brain or of the muscles of one eye, then objects are seen double. Besides which the fact, as shown by the stereoscope of Wheatstone, that a different image is thrown upon the two retinæ, demonstrates that both eyes are, under ordinary circumstances, employed in vision.

4th. Du Tour arrived at the conclusion that the mind cannot be simultaneously affected by two corresponding points of two images, and therefore that though two images may be formed in the eyes, only one of these is perceived. He was lead to this opinion by some experiments he made in which he presented two different colours to corresponding parts in the two retinæ. If a blue disc be presented to the right eye and a yellow disc to the corresponding part of the left eye, instead of a green disc, which would appear if these two colours had mingled before their arrival at a single eye, the mind will perceive the two colours, one or the other alternately predominating either partially or wholly over the disc.

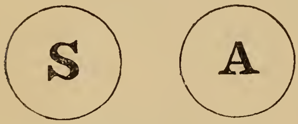

Fig. 159.

Mr. Wheatstone has perceived an analogous phenomenon. If s a, Fig. 159, is each presented at the same time to a different eye, the common border will remain constant, while the letter within it will change alternately from that which would be perceived by the right eye alone to that which would be perceived by the left eye alone. At the moment of change the letter which has just been seen breaks into fragments, while fragments of the letter which is about to appear mingle with them, and are immediately after replaced by the entire letter. It does not appear to be in the power of the will to determine the appearance of either of the letters, but the duration of the appearance seems to depend upon causes which are not beyond our control; thus if the two pictures be equally illuminated the alternations appear in several of equal duration; but if one picture be more illuminated than the other, that which is less so will appear during a shorter time.

These experiments appear to show that when two dissimilar impressions are made upon the two retinæ the mind does not combine them together, but they do not prove that when the two impressions harmonize and suggest to the mind the same idea they are not attended to, in fact the inference which I should draw from the effects of these experiments would be the reverse of Du Tour. Inasmuch as both the colours are alternately seen in his experiments, and both the letters in Wheatstone's are perceived, I should conclude that both impressions had been conveyed to the sensorium, and so long as the images were equally vivid produced an equal effect upon it, as shown by the equal alternations in the perception of the one or the other dissimilar object, but that when the one image was thrown the more vividly upon the retina then the impression upon the sensorium was proportionally greater. If the impression upon the two retinæ be the same or harmonize, then of course no alternation can be perceived, and consequently the double impression cannot be proved, but I think the fair presumption is that each image produces its effect upon the mind.

5th. After the discovery of the insensibility of the optic nerve some persons attempted to explain the fact of single vision by the supposition that half of an object fell upon the nerve of one eye, and the other half of the object upon the nerve of the opposite eye, and thus in reality that only a single image is formed upon the sentient surface, the half of it being in each eye. That this may be true in some cases is quite possible as Fig. 160 will show, but that it can generally occur is so obviously impossible, that it need only be mentioned. It would require that in all cases the images of all objects, no matter what their size, or their distance, or their position, should always be thrown upon precisely the same points of the retinæ, and if not of absolutely the same size, at least that they should never cover more than the half of the optic nerve, and that this should

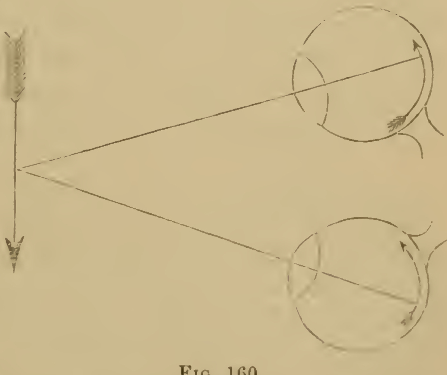

Fig. 160.

always be equally covered in each eye, which certainly cannot happen.

6th. The theory which has obtained by far the most general support is, that there are certain parts in the two retinæ which correspond, and that so long as the images of objects fall upon these corresponding points do they give rise to the perception of one object, but immediately the images do not fall upon these points double vision is the result. That there are such corresponding points is certain. If, when in the dark, we press upon the upper part of both eye-balls a single luminous spot is seen in the middle of the field of vision below; if the lower part of both eye-balls be pressed upon then a single spot is seen in the middle of the field of vision above; but if the upper part of one ball, and the lower part of the other, are pressed upon then two luminous spots are seen, the one above, the other below: therefore the upper parts and the lower parts of the two retinæ agree. If the inner sides of the two eyes are pressed upon, two luminous spots are seen, and so also if the two outer sides of the eyes are pressed upon, two spots are perceived; but if the inner side of one eye and the outer side of the other are pressed upon together, a single spectrum will be perceived in the opposite direction to that in which the pressure is made, showing that the inner side of one eye coincides with the outer side of the other eye. Fig. 161 will illustrate this. Suppose A to represent the left, and B the right eye, the points *d* and *d′*, *b* and *b′* will correspond, as also will *c* and *c′*; or if we suppose the two retinæ to be placed the one within the other, as in C, it will at once be seen that the right sides, the left sides, the upper parts, and the lower parts, and so also all the intermediate points of the two retinæ correspond exactly; so that taking the axes of the retinæ as the pole, all points which lie at equal distances in the same direction are identical in sensation, and if excited simultaneously only one object will be perceived; but all the other points are not identical in sensation, and when two such points are excited, as *d* in A and *b′* in B, two objects will be perceived, precisely as

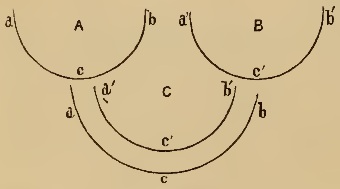

FIG. 161.

though two points in the same eye a and b in A, or a' and b' in B, had been impressed with the image.

It has been shown that when the axes of the eyes are accurately directed to an object it will appear single. Now in this case the images must fall upon corresponding points of the two retinæ, and this must invariably happen where the optical axes converge at the object, as is shown in Fig. 162, in which, as Müller has shown, objects which lie at the side of the centre of the field may also appear single.*

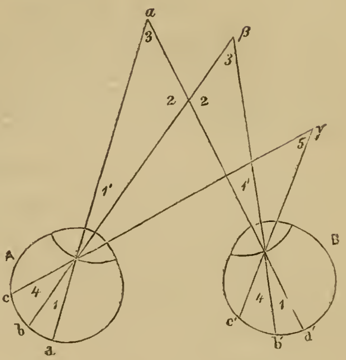

Fig. 162.

If the axes of the eyes A and B be so directed that they meet at a, an object at a will be seen singly at the same spot in the middle of the field of vision, for the point a of the one retina and a' of the other are identical. But other objects also, which lie to the side of a, for example β and γ, may also appear single. If the object β be so situated that its image falls in both eyes at the same distance from the central point of the retina, namely at b in the one eye and at b' in the other, the image of β affecting identical parts of the retinæ will appear single. In the same way γ will be seen single if the distance of the point of the retina c from the point a in the eye A be the same as that of the point c' from the point a' in the eye B.

This theory of single vision appears to be so satisfactory that it has been adopted by many of the most able men in the departments of metaphysics and mathematics, and amongst anatomists and physiologists it is almost universally received. Amongst others the names of Galen, Briggs, Newton, Reed, Rohault, Hartley, Wollaston, Smith, Müller, and Alison, may be mentioned as having adopted it.

But, supposing this doctrine of corresponding points to be true, it is merely a statement of fact and does not in any way explain the cause of it. Dr. Reid, who in his work "On the Human Mind" enters at length upon a consideration of this question, thinks that the most plausible attempts to account for it have not been successful, and considers it to be a primary law of our constitution or the consequence of a more general law, which is not yet discovered. This, when put into simple language, really means that he considers we know nothing about it. That it is an innate property is certain. The cause of it must be a structural one, either in that part of the brain to which the two optic nerves proceed and there give rise to perception, or to the manner in which the fibres of the optic nerves are connected together and are then distributed to the eyes.

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* Müller's Physiology, by Baly, vol. ii.

7th. Though the notion found support in the subtile reasoning of Bishop Berkeley, it is in the highest degree improbable that single vision from two images is merely the result of custom and experience or of the influence of the mind alone. In no other instance do the corresponding nerves of the two sides of the body act so simultaneously as to refer the sensations to one spot: and in no other instance do we find the same intimate union between the two corresponding nerves as takes place in the optic nerves, neither do we find in any other organs of sensation the same consentaneousness of action in all their parts as exist in the eye. These have frequently been spoken of when describing their structure, and the intimate relation which they possess has just been illustrated in the effect of two different colours or dissimilar figures upon the two eyes. In connexion with this question of single vision it is a matter of great interest to determine the exact arrangement of the fibres in the chiasma or commissure of the optic nerves. That it varies in different animals is certain, and this variation, inasmuch as a corresponding variation in the direction of eyes of animals is also found, corroborates the idea that it is intimately connected with singleness of vision: for where the eyes are so directed, as in man, that the axes are parallel, there the most intimate union of the nerves occurs, while in those animals whose eyes are placed so laterally that they cannot both be directed at the same time upon the same object, as in fish, there the optic nerves do not commingle, but simply cross each other, that of the right eye passing to the left side of the brain, and that of the left eye to the right side of the brain. While in other creatures, whose eyes are so placed that the axes cannot converge to the same point of an object, but which, nevertheless, are not placed so laterally that they cannot both at the same time be so directed as to receive an image of an object, as is the case in birds and many quadrupeds, the arrangement of the commissural fibres is different from that found in man.

In man it is certain that many of the fibres of the nerve in connexion with the right side of the brain pass to the left eye, others proceeding onward to the right eye, and similarly with the left nerve. I have also little doubt that some fibres pass directly from one retina to the other without going to the brain at all, and also that some fibres which pass from the brain along one tractus, as far as the commissure, return to the brain along the other tractus without proceeding to the eye at all; and further it is highly probable, if not certain, that in the central parts of the sensorium, at the quadrigeminal or bigeminal bodies, as the case may be, to which the optic nerves proceed, the fibres are with those of the two sides of the brain intimately connected together. So that in the chiasma there is not only a decussation of the middle portion of the fibres of the two nerves, but a double commissure, one on the anterior curve of the junction, belonging to the two retinæ, and the other on the posterior curve belonging to the brain. This arrangement I found in dissections of the brain of pigs made at least twenty-five years ago, and which I have since found in other animals as well as in man. Fig. 163 is a drawing of this structure in man, the part being opened out and enlarged. Arnold gives a very similar view of the arrangement of fibres in the commissure.

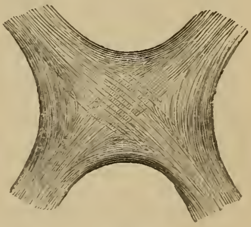

FIG. 163.

The connexion of the optic nerve with the brain is commonly described as with the nates and testes—or optic tubercles, as they have in consequence been called, but it is in reality far more extensive, for though many of the fibres may be evidently enough traced to these bodies, which always exist where eyes are found, fibres from the nerves may be followed to other parts of the central mass. Thus, beginning with the chiasma, we find the posterior edge connected by grey cerebral matter with the pituitary body, the tuber cinerum, and the infundibulum; while the anterior edge of it is connected with the lamina cinerea, below the anterior extremity of the corpus collosum, from which some fibres are continued through the grey matter into the optic nerve and pass along the nerve of the same side, not decussating; above the chiasma the tuber cinerum and the lamina cinerea are continuous. The tractus then passes backwards round the crus cerebri to which, especially by its anterior edge, it is closely connected. The fibres mount upwards and when spread out three principal portions may be traced: one anterior broadly expands over the whole thalamus, forming its exterior white fibrous part, some of the fibres pass into the structure of the thalamus, while the posterior extend to the nates; and some of the fibres may be traced to the broad soft middle commissure of the brain. A second smaller and less distinct posterior and inferior portion joins the crus cerebri, with which it passes above the pons varolii, where its fibres are lost in those of the crus: and a third middle portion, thick and distinct, which passes to both, but particularly to the posterior, of the quadrageminal bodies; some of these fibres from the two opposite sides join in the commissure of the quadrageminal bodies, some few also pass to the transverse base of the pineal gland and thence to its pillars, while other fibres again are continuous with that band which passes from the testes to the cerebellum—the processus e cerebello ad testem. So that we have the optic fibres most extensively connected with the most important cerebral masses, and also joining each other in the median line. The three Figs. 164, 165, 166 will illustrate the manner in which different persons have supposed the fibres of the two nerves are related to each other. In Fig. 164 it is supposed that each fibre of the cerebral portion of the nerve divides in the commissure into two portions, which

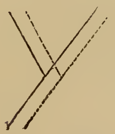

Fig. 164.

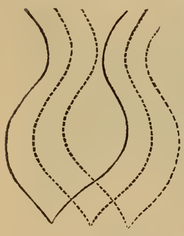

Fig. 165.

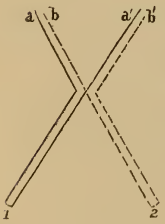

Fig. 166.

pass to the corresponding parts of the two retinæ; in Fig. 165 it is conjectured that each retina and optic nerve contain exactly the same number of fibres, and that the corresponding fibres are united in the brain; and in Fig. 166 that the corresponding fibres in the two retinæ spring from, or are connected with, the same point in the brain, and in the commissure divide into the filaments which proceed to the retina of each eye. Thus, 1 proceeding from the left side of the brain divides into two branches, one of which passes to the right eye and the other to the left; and so also with 2, which proceeds from the right side of the brain. Thus the left optic nerve consists of an equal number of fibres *a* which proceed from the left side of the brain and *b* which pass from the right side; so also with the fibres *a′* and *b′* which form the right optic nerve. But of the minute arrangement of the fibres nothing is satisfactorily demonstrated farther than above stated, these opinions being merely ideal. In fish, where the eyes are situated so laterally that only one of them can receive at the same time the image of an object, it is probable there are no corresponding points in the two retinæ; but in birds and in most quadrupeds where the eyes are generally so placed, that although their axes diverge, and cannot be made to meet in one point of an object, they are not so laterally situated but that an image is formed in both eyes. Either they must see double, the relation between the different parts of the retina is not the same as in man, or the theory of corresponding points is incorrect. That these creatures see objects double no one can believe, and Müller, who strenuously contends for the correctness of the theory of corresponding points, explains the difficulty by supposing that in man, and these quadrupeds, and birds, the corresponding points of the retinæ differ. Where an animal regards an object situated directly

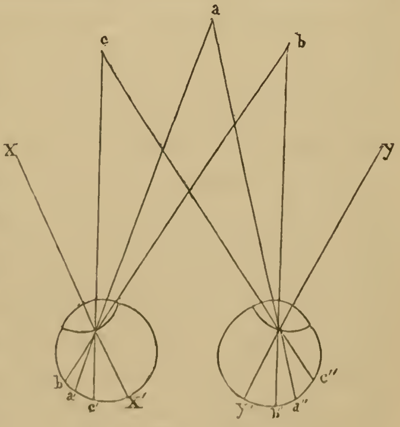

FIG. 167.

in front of it the image of the object must fall in both eyes on the outer portion of the retinæ. Thus the image of the object *a*, Fig. 167, will fall at *a′* in one eye and at *a″* in the other; and these points *a′* and *a″* must be identical: in fact, a dog alters the direction of its eyes according to the distance of the object viewed, and the direction of his body, just as we do. But the visual axes are not in the dog identical with the axes of the eyeballs; the visual axes in the dog are not *yy′* and *xx′*, but the lines *aa′* and *aa.″* For distinct and single vision of objects, as *b a c* lying in front of the animal and visible to both eyes, it is necessary that the points *b′* and *b″* or *c′* and *c″* in both retinæ on which the images of these objects fall should be identical. All points of the retina in each eye which receive rays of light from lateral objects only, can have no correspondent identical points in the retina of the other eye; for otherwise two objects, one situated to the right, the other to the left, would appear to lie in the same spot of the field of vision. It is probable, therefore, that there are in the eye of animals parts of the retinæ which are identical and parts which are not identical—having no correspondent parts in the other eye. This relation of the two retinæ to each other may be illustrated by Fig. 168, in which portions of the outer parts of the two retinæ are superimposed upon each other where they correspond, the other parts not being identical. The corresponding points are indicated by the same letters as in Fig. 167.

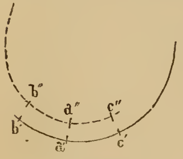

Fig. 168.

This explanation of Müller is ingenious, and supposing the theory of corresponding points in the retinæ of man be correct is necessary to explain the want of parallelism in the axes of the eyes of animals. It cannot however be considered as any proof of the correctness of the theory of single vision resulting from corresponding points in the retinæ, but only as an ingenious attempt at explaining a difficulty, and there are some persons who would regard it as more plausible than satisfactory. Indeed, Professor Wheatstone has denied the correctness of the theory: and declares that the image depicted in the one eye differs materially in form from that in the other eye; the true perception of the shape of an object resulting, according to him, from the sensorium receiving an impression from these two dissimilar images; whether the theory is compatible with the fact shown by the measurements of the relative position of the entrance of the optic nerve is at least doubtful. Those measurements I think clearly prove that whatever part the fibres of the optic nerve play in the phenomenon of vision—and they probably only convey to the sensorium the impression received by the true retinal elements—that the greatest number of them are distributed on that part of the eye-ball where there is the greatest range of vision, see page 129, *et seq:* the extent of vision being always in conformity with the space of retina on that side of the optic nerve; and as the rods and cellules always are in proportion to the abundance of the fibres, that side of the retina which receives the greatest number of images, is most exercised, or where the range of vision is the greatest, is always the largest. This is a fact, which I think a careful comparison of the position of the eyes in the head, the size of the eye-ball, and the place of entrance of the optic nerve into it, with the habits of the creature, will render more obvious than a casual glance would do. To mention only a few instances as illustrations, man, from the erect position of his body, the horizontal placing of his eyes, and his habits, has a more equal panoptic range than almost any other creature; and in him the optic nerve enters the ball not far from the centre, leaving, however, a somewhat shorter space on the inner and lower parts of the retina than on the upper and outer. While he enjoys a free range of vision above the horizontal line, there are far more occasions for him to look below than above this line, and certainly more images fall to the outer and upper sides of the entrance of the optic nerve than to the inner and lower sides of this spot. In the pig, who sees at no great range before him, and who seeks his food with the snout in the ground, whose head consequently is almost always downwards and near the ground, the nerve enters the eye more outwardly and much lower than it does in man: the pig wants not to see far before him, but he does require while grubbing to look behind him from whence danger comes. So with the timid herbivorous animals; look at the entrance of the nerve in the bullock and sheep, who pass so much time with the head near to the ground in open places, where danger usually comes from behind, the upper and inner sides of the retina are much larger than the lower and outer surfaces; while in deer* who live in more wooded places, where danger is also from the front, though the inner or anterior still is larger than the posterior surface of the retina, it is not so to the same extent as in bullocks, while the upper side is very considerably larger than the under, as in sheep and bullocks. The same variation exists in different birds, reptiles, and fish, as the tables will show.

Perspective projection of images on retina.—Wheatstone says that when an object is viewed at so great a distance that the optic axes of both eyes are sensibly parallel when directed to it, the perspective projections of it, seen by each eye separately, are similar, and the appearance to the two eyes is precisely the same as when seen by one eye only. There is in such case no difference between the visual appearance of an object in relief and its perspective projection on a plane surface; and hence pictorial representations of distant objects, when those circumstances which would prevent or disturb the illusion are carefully excluded, may be rendered such perfect resemblances of the objects they are intended to represent as to be mistaken for

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* At the time the tables of measurement of the eyes of animals were printed, page 131 *et seq.*, I had not had the opportunity of measuring the dimensions of the deer's eyes. Through the politeness of H. C. M. Ingram, Esq., of Temple Newnam, I have since done so. They are as follows, in inches and thirtieths of an inch:—

	Right.	Left.
Antero-posterior circumference, vertical	3·22	3·22
Do. do. horizontal	3·23	3·23
Transverse do.	4·1	4·1
Diameter, antero-posterior	1·5	1·5
Do. vertical	1·7	1·9
Do. horizontal	1·9	1·9
From centre of optic nerve to outer or posterior margin of cornea	1·5	1·4
Do. to inner or anterior margin	1·9	1·10
Do. to upper margin	1·22	1·22
Do. to lower margin	1·3	1·2
Transverse diameter of cornea	1·7	1·7
Vertical do.	1·0	·29
Length of cord of cornea, transverse	·28	·29
Depth of curve of cornea	·10	·9

The cornea is egg-shaped, the inner curve being much larger than the outer: the upper line of the cornea is decidedly straighter than the lower, which is much more curved.

them: the Diorama is an instance of this. But this similarity no longer exists when the object is placed so near to the eyes that to view it the optic axes must converge: under these circumstances a different perspective projection of it is seen by each eye, and these perspectives are more dissimilar as the convergence of the optic axes becomes greater. This fact may be easily verified by placing any figure of three dimensions, an outline cube for instance, at a moderate distance before the eyes, and, while the head is kept perfectly steady, viewing it with each eye successively, while the other is closed. Fig. 169 represents the two perspective projections of a cube; B is that seen by the right eye, and A that presented to the left eye, the figure being supposed to be placed about seven inches immediately before the spectator.

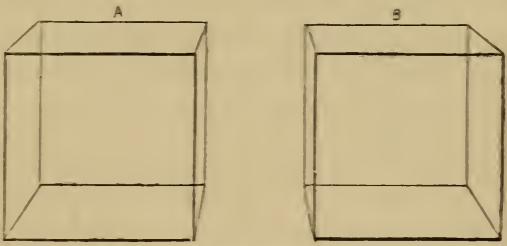

FIG. 169.

The appearances which are by this simple experiment rendered so obvious may be easily inferred from the established laws of perspective; for the same object in relief is, when viewed by a different eye, seen from two points of sight at a distance from each other equal to the line joining the two eyes. This fact may also be with the utmost ease rendered evident by holding a paper-cutter, a thin book, or, indeed, many other bodies horizontally on a line with the eyes at a little distance from the face, and with one end towards it, by shutting first one eye and then the other, we shall be at once conscious of a different impression made in the two eyes; the distance at which objects will project different images upon the two retinæ varies somewhat in different persons, and depends upon the distance between the centres of the two eyes, which in most people is about two and a-half inches. The angle formed by lines drawn from the centre of each eye to the object looked at, constitutes what is called the binocular parallax of such object. This angle, supposing the object to be twelve feet distant, and the space between the eyes to be two and a-half inches, would be exactly one degree, and at twenty-four feet half a degree, so that it is evident it is only objects near to the eye in which this dissimilarity of images exists, for in the more distant the binocular parallax is too small to produce any effect: in those persons in whom the eyes are widely separated the binocular parallax will be greater and consequently the appearance of relief proportionally greater, and in those in whom the eyes are near together it will in a corresponding degree be less.

It is therefore obvious why it is impossible for the artist to give a perfectly faithful representation of any near solid object, that is to produce a painting which shall not be distinguished in the mind from the object itself. When the painting and the object are seen with both eyes, in the case of the painting two similar images are projected on the retinæ, in the case of the solid object the images are dissimilar, there is therefore an essential difference between the impressions on the organs of sensation in the two cases, and consequently between the perceptions formed in the mind; the painting cannot therefore be confounded with the solid object.

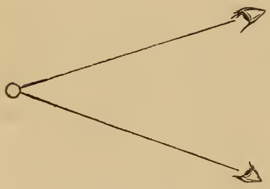

Fig. 170.

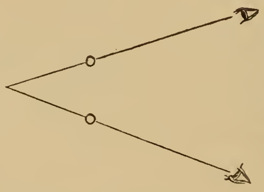

Fig. 171.

In order to prove the correctness of this statement Mr. Wheatstone contrived to make the pictures of two precisely similar objects each fall upon the corresponding points of each eye. This may be done by placing two similar objects in exactly the direction of the optic axes, either before or beyond their point of intersection, as shown in Figs. 170, 171, 172. Fig. 170 represents the usual situation of an object at the intersection of the optic axes, in Fig. 171 two similar objects are placed in the direction of the optic axes

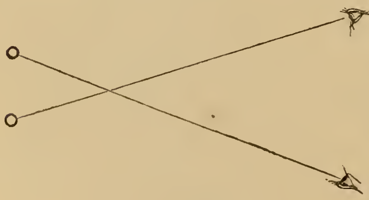

Fig. 172.

before their point of intersection, and in Fig. 172, beyond this point. If not so placed, or the eyes are not accurately fixed, two objects will be seen in consequence of the images of the two objects falling upon dissimilar portions of the two retinæ. As it is difficult to make this experiment with the naked eye Mr. Wheatstone invented two simple instruments which easily enabled it to be made, and found that if instead of placing two exactly similar objects the two prospective projections of the same solid object be so disposed the mind will still perceive the object to be single, but instead of a representation on a plane surface, as each drawing appears to be when separately viewed by that eye which is directed towards it, the observer will perceive a figure of three dimensions, the exact counterpart of the object from which the drawings were made. To exhibit the effect of two such similar pictures upon the eye Wheatstone invented a reflecting stereoscope which essentially consists of two mirrors placed with their backs towards each other at an angle of 90°, with two sliding frames upon which the pictures may be attached and properly adjusted. The observer then placing his eyes as near as possible to the mirrors, taking care that the back of them is in the centre between the eyes, will see one object from the two drawings, or rather the reflections of the two drawings, and, if the perspective in the drawings be accurate, the object represented will appear in its triple dimensions, or in relief, as the actual object itself would have done. In this manner the most complex figures of three dimensions may be accurately represented to the mind by presenting their two perspective projections to the two retinæ. Figs. 173 and 174 are copies from some perspective projections which Wheatstone has figured; they may be indefinitely varied at pleasure.

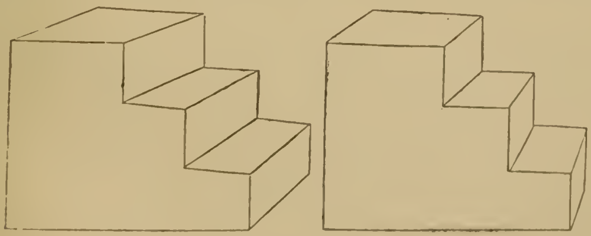

FIG. 173.

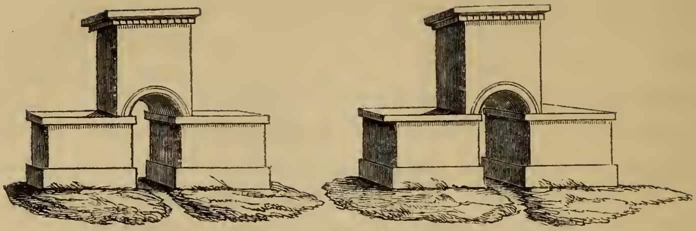

FIG. 174.

Brewster invented soon after Wheatstone had demonstrated these curious facts another form of stereoscope,* in which the rays from the two pictures are made to diverge to the desired distance by means of two eccentric double convex lenses placed in sliding tubes, so as to be drawn in and out to suit different eyes, and by which, within certain limits, any desired magnifying effect may be produced. This is the form of instrument with which almost everybody is now familiar, and which has rendered stereoscopic pictures and their surprising effects so well known. It may, however, be proper to state that with this instrument the effect is almost always much exaggerated, for with nearly all the more extended views and large objects in landscapes when seen with the eyes in nature, for the reason just explained, there is little or no dissimilarity in the two retinal images, whereas in the two views for the stereoscope the angle is usually great, purposely so, with the intention of producing an exaggerated effect; hence the boldness of relief in these views is such as to surprise and charm the mind almost more even than the objects themselves. This is effected by taking the two views for the right and left eyes at a much greater angle than the objects are themselves presented to the eyes. Thus, supposing in taking the two views of a building, the distance between the photographic cameras be thirty inches, as the distance between the eyes is only two and a half, the proportion in the stereoscopic parallax is to the natural binocular parallax as twelve to one, and the perspective and relief of the building in the views will be twelve times stronger and more vivid than that produced by looking on the building itself from the spot where the pictures were taken.

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* Brewster, in a History of the Stereoscope, denies that Wheatstone was the discoverer of the fact of two dissimilar pictures being painted upon the retina by near objects, which he says was well known to Euclid more than two thousand years ago, and has been recognised by many other persons since, and particularly was pointed out by Mr. Elliot, of Edinburgh, who even constructed a stereoscope. Be this as it may, it is certain the discovery attracted no attention, and was even neglected, if not altogether forgotten, by Elliot himself, who never appears to have pursued the subject to a practical end. I cannot therefore help thinking that much of the merit claimed by Wheatstone is really due to him, for until his instrument it does not appear any other was effective, or that he knew of Elliot's investigation. See Brewster on the Stereoscope, in the National Magazine, vol. i. p. 10.

To this declaration of Wheatstone that a different image is formed in each eye, and that it is owing to the combination by the mind of these two dissimilar images that we owe, if not entirely, at least in a great degree our belief of the solidity of an object having three dimensions, an obvious and weighty objection may at once be raised; of how it then happens that a person having only one eye, or possessing two, shuts one, has a perfectly correct notion of solid bodies in their triple dimensions, never mistaking them for plane surfaces variously shaded, as he ought to do according to this doctrine? This difficulty Wheatstone has foreseen and met in the following manner. He says to explain these apparent difficulties, it must be kept in mind that although the simultaneous vision of two dissimilar pictures suggests the relief of objects in the most vivid manner, yet there are other signs which suggest the same ideas to the mind, which, though more ambiguous than the former, become less liable to lead the judgment astray in proportion to the extent of our previous experience. The vividness of relief arising from the projection of dissimilar pictures, one on each retina, becomes less and less as the object is seen at a greater distance before the eyes, and entirely ceases when it is so distant that the optic axes are parallel while regarding it. We see with both eyes all objects beyond this distance precisely as we see near objects with a single eye; for the pictures on the two retinæ are then exactly similar, and the mind appreciates no difference whether two identical pictures fall on corresponding parts of two retinæ or whether one eye is impressed with only one of these pictures. A person deprived of the sight of one eye sees therefore all external objects, near and remote, as a person with both eyes sees remote objects only, but that vivid effect arising from binocular vision of near objects is not perceived by the former: to supply this deficiency he has recourse unconsciously to other means of acquiring more accurate information. The motion of the head is the principle means he employs. That the required knowledge may be thus obtained will be evident from the following considerations. The mind associates with the idea of a solid object every different projection of it which experience has hitherto afforded; a single projection may be ambiguous, from its being also one of the projections of a picture, or of a different solid object; but where different projections of the same object are successively presented they cannot all belong to another object, and the form to which they belong is completely characterized. While the object remains fixed, at every movement of the head it is viewed from a different point of sight, and the picture on the retina consequently continually changes. Every one must be aware how greatly the perspective effect of a picture is enhanced by looking at it with one eye only, especially when a tube is employed to exclude the vision of adjacent objects whose presence might disturb the illusion. Seen under such circumstances from the proper point of sight, the picture projects the same lines, shades, and colours on the retina, as the more distant scene which it represents would do were it substituted for it, the appearance which would make us certain that is a picture is excluded from the sight, and the imagination has room to be active. Several of the older writers erroneously attributed this apparent superiority of monocular vision to the concentration of the visual power in a single eye.*

Whether this explanation may be considered by others as satisfactory as it is to Wheatstone I know not. To myself I must confess it is not altogether so evident as to lead to the conviction of the untruthfulness of the theory of corresponding retinal points. Nor am I quite sure that the imperfection of vision with a single eye is not overstated. Indeed the experiments of Wheatstone himself would appear in some degree to show that the theory of single vision resulting from corresponding points of the two retinæ being similarly affected is correct, for it is necessary in his experiments both with the objects and the perspective pictures of them, that these should fall accurately upon like points in the two eyes, otherwise, instead of the perception of one object in relief, two objects or pictures are seen. This much however is certain that the experiments of Wheatstone are of that precise and demonstrative character and the ability of the observer so great as to render his opinion of the highest importance, so that it must be confessed that the efficient cause of single vision from two eyes depends upon organization so minute, and arrangement of matter of so delicate a nature, as hitherto to have escaped such an unravelling as to make it possible to demonstrate the absolute correctness of any explanation. That the true cause of single vision will hereafter be indisputably shown there is no reason whatever to doubt.

---

* "We see more exquisitely with one eye shut than with both, because the vital spirits thus unite themselves the more, and become the stronger; for we find by looking in a glass whilst we shut one eye that the pupil of the other dilates."—*Lord Bacon's Works, Sylva Sylvarum, art. Vision.* Wheatstone in Philosoph. Transactions for 1838, page 381.

In the meanwhile it is to be remarked, not as offering a solution of the difficulty, but as showing that single perception from a double impression should be considered in a more general manner than the question frequently has been as one peculiar to the eye, that it must not be looked upon solely as an optical phenomenon to be solved by any mere laws of vision, but as one which is common to all the senses and must be solved by some general law common to all of them. We touch an object with both hands, yet we regard it as a single substance, we hear a sound by each ear, yet there is but a perception of a single sound, an odour is perceived by both nostrils, and a taste by both sides of the tongue, yet these are recognised as single sensations in a natural state of the organs and the system, for like vision they all under certain circumstances become double; with touch and sound obviously the impression is as distinctly double as it is in the eye, and though with smell and taste it is not at first consideration so obviously so, there can be no doubt that it really is, for there is in all equally a nerve on each side of the median line. Now while this does not lessen the real difficulty it shows it to be part of a general law common to all the senses and probably dependent upon the organization of the sensorium or the central union of the parts, as well as the particular organs. There is, however, this important difference in the eye and the other senses, except that of touch, that whereas we can at pleasure see a single object double we cannot at will hear a single sound as two, this may be one cause of the interest which single vision from two pictures has excited, another probably being that it is not difficult actually to see the images painted upon the retinæ; whereas in the other senses nothing of so material a nature is presented to our notice. These considerations will serve to remove the phenomena from the purely optical to those in which sensorial considerations must also be taken into account.

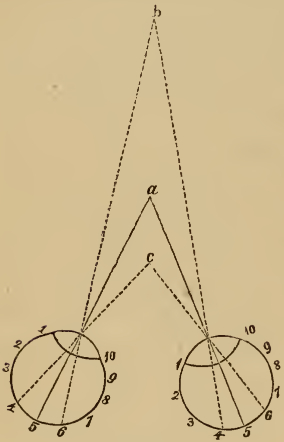

Fig. 175.

Double vision.—Everybody must be conscious of at times seeing objects double which are known to be single. The reason of this having been explained at page 348 *et seq.* and shown by Fig. 157, but little space need now be occupied with it, but probably Fig. 175 will serve to render the matter clearer and may therefore be introduced. Let *a* be a point to which the axes of the eyes are directed, and *b* an object more distant from the eyes. An image of *a* will fall upon identical points of the two retinæ, namely upon the central points 5, 5, *a* will consequently be seen single. The image of *b* will fall in the left eye at 6 and in the right eye at 4. The points 4 and 6 of the two eyes being non-identical, since the corresponding points in the two eyes are each marked 4, *b* will be seen double, and the distance between the two images of *b* in proportion to the extent of the whole field of vision will be the same as that between 4 and 6, in comparison with the distance between 1 and 10 in each retina. So an object at *c* being nearer to the eyes than the point of convergence will appear double, as the image of it will fall in the left eye at 4, in the right at 6, the distance separating the two images, as in the former case of *b*, being as the distance between 4 and 6 is to the whole of the retina.

Long and short sight.—It is well known that there are two very contrary defects in the eyes of different persons. In the one objects can only be seen with distinctness when brought very near to the eye; all objects beyond a certain distance appear indistinct. From the necessity existing for such a person to bring all objects near to the eye this defect is called shortsightedness, or from the contraction of the eyebrows and lids which commonly accompanies it, *myopia.* It is very frequently found in young persons and in people of studious habits, who are accustomed principally to use the eyes for near objects.

The other defect is of an opposite character, *longsightedness,* in which near objects are very indistinctly seen, while distant things are seen with clearness. From this being very rarely observed under the middle period of life (except as the result of disease or original malformation), and very commonly in old age, it is called *presbyopia.*

Shortsightedness arises from the optical parts of the eye possessing too great a refractive power, owing to which the rays proceeding from distant objects are brought to a focus before they reach the retina; while the rays proceeding from a near object being more divergent are not brought to a focus at a point so near to the lens, and consequently reach the retina, and there form an image. This great refractive power may result from a greater density of the cornea or lens, but far more commonly it arises from the plumpness and rotundity of the eye from an abundance of the humors, and hence the increased curvature of the cornea and lens. This is to a certain extent natural to the young and, indeed, if not in excess is hardly to be regarded as a defect, and may be an advantage, inasmuch as it will allow of that flattening, which almost invariably takes place in the eye with advancing age, to occur without inconvenience. The remedy for this defect is an easy and effectual one: those rays which are not sufficiently diverging are to be rendered more so in order that they may not be collected into a focus until they reach the retina. This is to be accomplished by interposing between the object and the eye a concave lens; and by adjusting the dispersive power

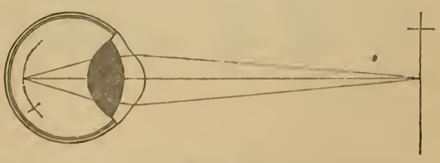

FIG. 176.

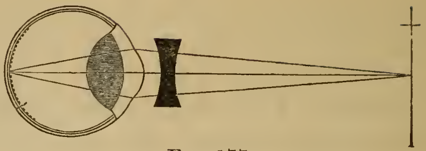

Fig. 177.

of the artificial lens to exactly counterbalancing the too great refractive power of the lenses of the eye, the image may easily be made to fall upon the retina, and thus distinct images of objects more or less distant may be obtained. Fig. 176 will at once illustrate the defect of the eye, and Fig. 177 the action of a concave lens in rectifying the too great convergent power of it.

Longsightedness results from the refractive powers of the eye being only sufficient to concentrate parallel, or but slightly divergent, rays upon the retina, while those rays which proceed from near objects are only collected into a focus behind it. Hence such persons can see well and distinctly distant objects, but all near things are indistinct. This defect does occasionally result from a congenital defect in the formation of the cornea or lens, or insufficiency of aqueous humor, but far more usually it is the result of advancing age, in which there is an almost invariable tendency for the eye to become less plump; there is then less of the aqueous humor and the cornea becomes flatter, as also does the crystalline lens, though the change in this latter is somewhat compensated for by its increase of density. The obvious remedy for this defect is to render the divergent rays less divergent, and this is readily accomplished by interposing between the object and the eye a convex lens, so that the eye is enabled to collect the rays into a focus nearer to the lens and consequently upon the retina. Fig. 178 will show the effect of a too flat eye, and Fig. 179 the action of a convex lens.

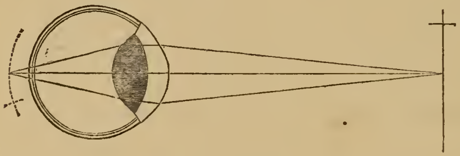

Fig. 178.

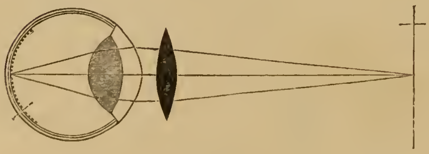

Fig. 179.

It may be proper to mention that in choosing glasses whether concave or convex those should be carefully selected which render objects clear without altering their size. It is the effect of the concave lens to diminish and of the convex to magnify all objects; as however the reason for their employment as spectacles is not on account of these properties, but to counteract a defect of the eye, we should be careful so to adjust the lens to the eye that the defect of one may correct that of the other without allowing it to preponderate. Each eye should be separately adjusted, more especially in exaggerated cases, such as are hardly to be considered, so to speak, normal, for it will be found, far more commonly than some Ophthalmic surgeons are inclined to admit, that there is a decided difference in the focal length of the two eyes.

It has been said that shortsightedness is a common defect among the studious. There is no doubt that as the eye is capable of adjustment to vision at different distances; so by employing it almost exclusively upon near objects it gradually habituates itself to this distance, and near-sightedness is the result. So on the other hand persons who are not in the habit of regarding near or minute objects with attention, but who are principally employing the eye in watching distant objects, acquire the power of perceiving them at a much greater distance than the student can, while a minute examination of a very small and near object would be impossible to them. This accommodation of the eye is every day seen. Who ever saw a common soldier or a sailor in spectacles? and who does not know how common the use of concave glasses is in an assembly of learned and studious men? From this a practical hint may be taken. That those who are shortsighted should exercise the eye upon distant objects, while those who are longsighted should observe near objects; but as the latter is more a defect of age, it is not so important as the former, nor so likely to be improved by such means. It is a natural defect, whereas shortsightedness being frequently an acquired one, it is only reasonable to think it may, by an opposite proceeding to that which induces it, be at least to some extent corrected.

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